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TESTING OF HANDGUNS

Prepared by

Marvalaud, Inc.
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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A particular Colt and Smith and Wesson revolver model was systematically selected as most representative of handguns in use in law enforcement in this country. A low-pressure and a high-pressure ("P") commercial .38 Special ammunition was selected for firing tests. Fifty rounds of low-pressure ammunition was fired exclusively by both a Colt and a Smith and Wesson. Fifty rounds of high-pressure ammunition was fired exclusively by both a Colt and a Smith and Wesson. Measurements were made after each five rounds on each handgun. The peak pressures experienced by the Colt firing "P"		

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ammunition carry the cylinder very near its estimated fatigue limit, while the Smith and Wesson stays well below. Both show severe deformation around the hole in the recoil plate (or hammer nose bushing) which would surely lead to fracture of the material around the hole after not too many more rounds. In addition, a Halec eddy current crack detector instrument was used to establish the existence of severe plastic deformation in the body of the recoil plate by comparison to calibration experiments run on severely deformed simulated recoil plates. It would appear that the recoil plates for both the Colt and the Smith and Wesson could benefit from redesign.

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I. GENERAL

The intent of this effort has been to focus on problems of handgun failure which have been reported by law enforcement officers, and to scrutinize these problems using all available information as well as the investigative tools of the metallurgist. The purpose has been to gain a better understanding of the reasons behind the failures. At the outset, it was recognized that this represents a rather ambitious undertaking in which the diversity of handguns in use as well as the variety of reported failures could diffuse our efforts and blunt the utility of this study. It was decided that our first task was to examine the relative frequency of reported failures of various types and to assess the available information on the details of handguns and ammunition in common use. The aim of this first task was to redefine a more limited study which could be conducted in more detail and more completely. The task is described in the next section, identified "Analysis of the Problem". Subsequent sections describe the experimental approach employed, the results, and conclusions.

A second intent of this work is to evaluate steel and aluminum plates when used to defeat .38 Special "+P" and .357 Magnum ammunition fired at various angles of incidence. To add meaning to these measurements, velocity measurements were made on the above loads while using actual revolvers (instead of a more traditional Mann gun).

II. ANALYSIS OF THE PROBLEM

a. Types of Handgun Failure.

Several sources of information were used. First among these was data made available to Marvalaud by Mr. Stanley Golaski of the Ballistics Research Laboratory at Aberdeen Proving Ground.¹ This work had involved firing a large number of rounds through a large number of pistols and revolvers. Most of these, however, were not those weapons found to be in common use by law enforcement officers in this country. This became evident in the studies described in the next section on handguns in common use. Although difficult to summarize, it was concluded that the most evident failures in these firings was deformation of the recoil plate, or some form of firing pin malfunction which could be related to a deformed recoil plate.

A second source of information was a LEAA Survey made available to Marvalaud by Mr. R. C. Dobbyn of The N.B.S. Law Enforcement Assistance Laboratory.² This survey had contacted the police departments of all the 50 largest cities in the U.S., all 50 state police organizations, and a cross-section of city, county, and township departments spread across the U.S. With respect to handgun problems, more than half (55%) of the responding departments either said they had had no problems with their handguns in the last five years or left the question blank. Among those departments that described at least one problem, those problems associated with the cylinder were mentioned most frequently (35%). The hammer / firing pin was reported to have been involved in the handgun problems of about one-fifth of the departments mentioning problems. It should be noted that any given "source of the problem" is being identified and characterized in many cases by individuals not familiar with failure analysis, or even metallurgy for that matter. For example, comments such as "crystallized firing pin" or "crystallized hammer" were listed as examples of hammer/firing pin problems in this survey.

A final source of information was through informal discussion with C. Glass, S. Golaski, and W. Bruchey of BRL at Aberdeen Proving Ground, as well as R. Dobbyn of The N.B.S. Law Enforcement Assistance Laboratory. The latter two in particular had considerable information to contribute to the discussions.

Upon consideration of the information available, it was concluded that the firing pin/hammer problems were most likely associated with recoil plate deformation. We decided to single out the recoil plate for careful investigation. In addition, we chose to focus attention on the cylinder's response

¹ Contract No. Tir-25965, an agreement between the United States Government, Department of Treasury, and H. P. White Laboratory, Bel Air, Md., Vols. II and III, Sept. 1971.

² LEAA Police Equipment Survey of 1972, Vol. V: Handguns and Handgun Ammunition, LESP-RPT-0005.00, August 1975.

to the peak pressures it sees when firing various kinds of ammunition. It was further hypothesized that failure modes should manifest themselves after a relatively few number of test rounds - perhaps fifty or so. This was based largely on opinions formed when examining reference 1.

b. Types of Handguns in Common Use.

The LEAA Survey² mentioned in the previous section also examined aspects of types of handguns in use by law enforcement officers in this country. It estimated that there are 484,752 officers carrying handguns of various calibers while on duty in the U.S. Of these, 71% are estimated to be .38 caliber, 25% are .357, 1% are .45 caliber, 2% are 9 mm, and 1% are "other" calibers. So .38 caliber is the dominant choice (nearly three times as many as .357 caliber). Of those departments citing the .38 as their most used caliber, 50% used that caliber exclusively, and 40% listed the .357 as the second most used caliber. Of those departments listing the .357 as their most used caliber, none used that caliber exclusively, and 77% listed the .38 as the second most used caliber. Again, the .38 shows its popularity.

In the listing of most used handguns, 99% were revolvers. For the second most used handguns, 98% were revolvers. Both these numbers become 100% for the fifty largest departments in the country. Therefore, one can conclude a .38 caliber revolver is the most representative choice to typify handguns in use by law enforcement officers in this country. If one next looks at the reported barrel lengths when the most used handgun is .38 caliber, 80% of the guns reported have a barrel length of 3-5 inches. So now one can conclude a .38 caliber revolver with a 4-inch barrel is the most representative handgun.

Finally, 91% of the departments listed Smith and Wesson as the manufacturer of their most used handgun and 50% of the departments listed Colt as the manufacturer of their most used handgun. Obviously, some departments listed both Smith and Wesson and Colt.

In fact, 221 out of 442 departments listed Colt as the manufacturer of their most used handgun, and 403 out of 442 departments listed Smith and Wesson as the manufacturer of their most used handgun. Again, clearly many departments listed both Smith and Wesson and Colt. Some 16 departments out of 442 listed some other manufacturer. If one assumes that these latter 16 did not also list Colt or Smith and Wesson, then some simple arithmetic reveals that 198 out of 442 listed both Colt and Smith and Wesson. This leads to the conclusion that 5% listed Colt alone, 46% listed Smith and Wesson alone, 45% listed both, and 4% listed "other".

In summary, it is fair to choose .38 caliber revolvers with 4-inch barrels made by either Smith & Wesson or Colt as the most representative handguns. Among those made available to Marvalaud for this study, we had only one model of Colt in .38 caliber with a 4-inch barrel; that was Model D5540, the Colt Diamondback. We had two models of Smith and Wesson made available which met these criteria, Model 10-6 and Model 15-3. We also had Model 67 and Model 64, but both of these are in stainless steel, and we had no stainless steel Colts for comparison. We chose the Model 15-3 since both it and the Colt Model D5540 have adjustable sights.

c. Types of Ammunition in Common Use.

Referring again to the LEAA Police Equipment Survey², it was found that almost half of the responding departments were using lead bullets in their most used handguns. About one-fourth were using hollowpoint, and about 15% were using jacketed ammunition. About two-thirds reported using bullets of only one type in their most used handgun. About half of these said they used lead bullets exclusively. Thirteen percent reported using hollowpoint exclusively. About three-fourth of the departments reported using ammunition with bullet weights of 151-160 grains, and very few departments were using ammunition with bullet weights greater than this. About half of the responding departments were using at least some Remington-Peters ammunition with their most used handgun. About a third were using Winchester-Western, and 17% were using Super Vel ammunition. More than half were using only one brand of ammunition with their most used handgun. Fifty percent of these said they were using Remington-Peters exclusively. About one-fourth were using Winchester-Western. Less than 10 percent were using any other brand exclusively.

In summary, the choice of most common ammunition in use would be 158-grain lead round-nose made by Remington-Peters, with Winchester-Western running as a second choice.

d. Evaluation of Common Types of Ammunition.

Early in the program it was recognized that in order to evaluate the effects of some of the newer commercially available loads, it would be desirable (in fact necessary) to have some data on these loads as well as the more standard loads. As a result, in a related program, H. P. White Laboratory, Inc., Bel Air, Md., ran a series of tests to determine muzzle velocity, barrel time, and chamber pressure on five rounds of each of 65 cartridges representing seven calibers of a variety of bullet weights and types.³ Figures 1, 2, 3 and 4 show plots of peak chamber pressure versus muzzle velocity for the data (tabulated in the H.P. White report) for regular .38 Special ammunition. Figures 5 and 6 show the same for "+P" .38 Special ammunition. Finally, as a point of comparison, Figures 7 and 8 show the same for .357 Magnum ammunition. Table I lists the correlation between code letters in the figures and the type of ammunition tested. It was decided to select one .38 Special ammunition from the low-pressure extreme and one from the high-pressure extreme. "H", or Remington 158-grain lead round-nose was chosen as the best representative of the low-pressure extreme. It ranks 4th in terms of lowest (8.9 ksi) average pressure (behind "G", "F", and "K", respectively), but its widespread use (see section 2.3) dictated its selection. "Z", or Smith and Wesson 158-grain jacketed hollowpoint "+P" was

³ Test Report - "Interior Ballistic Tests of a Limited Sample of a Variety of Commercial Handgun Ammunitions" prepared for U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Md., by H. P. White Laboratory, Inc., Bel Air, Md. 21014, August 1976 under P.O. No. DAAD05-76-M-A498.

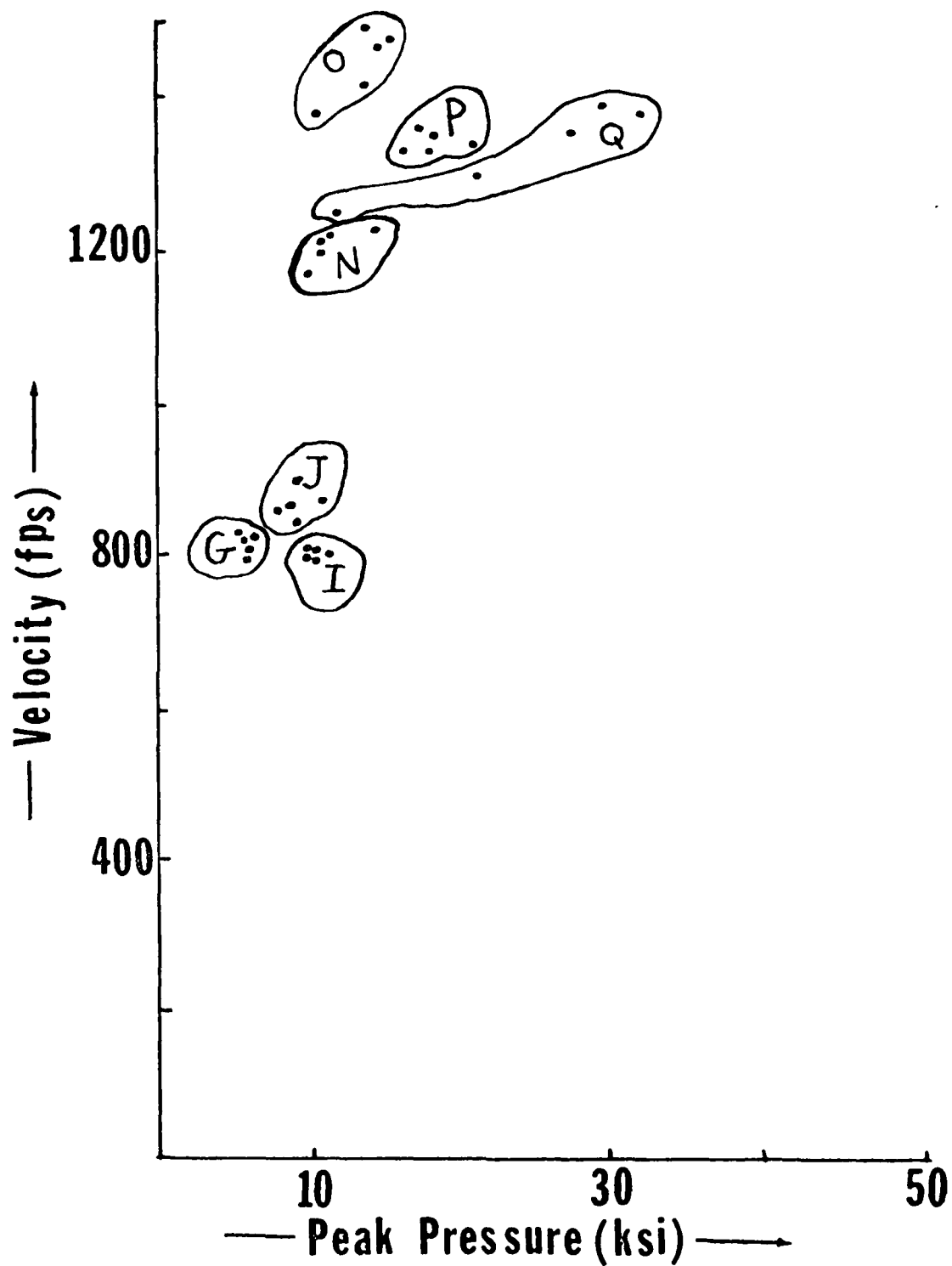


Figure 1. Pressure vs. Velocity for Some Commercial .38 Special Ammunition.

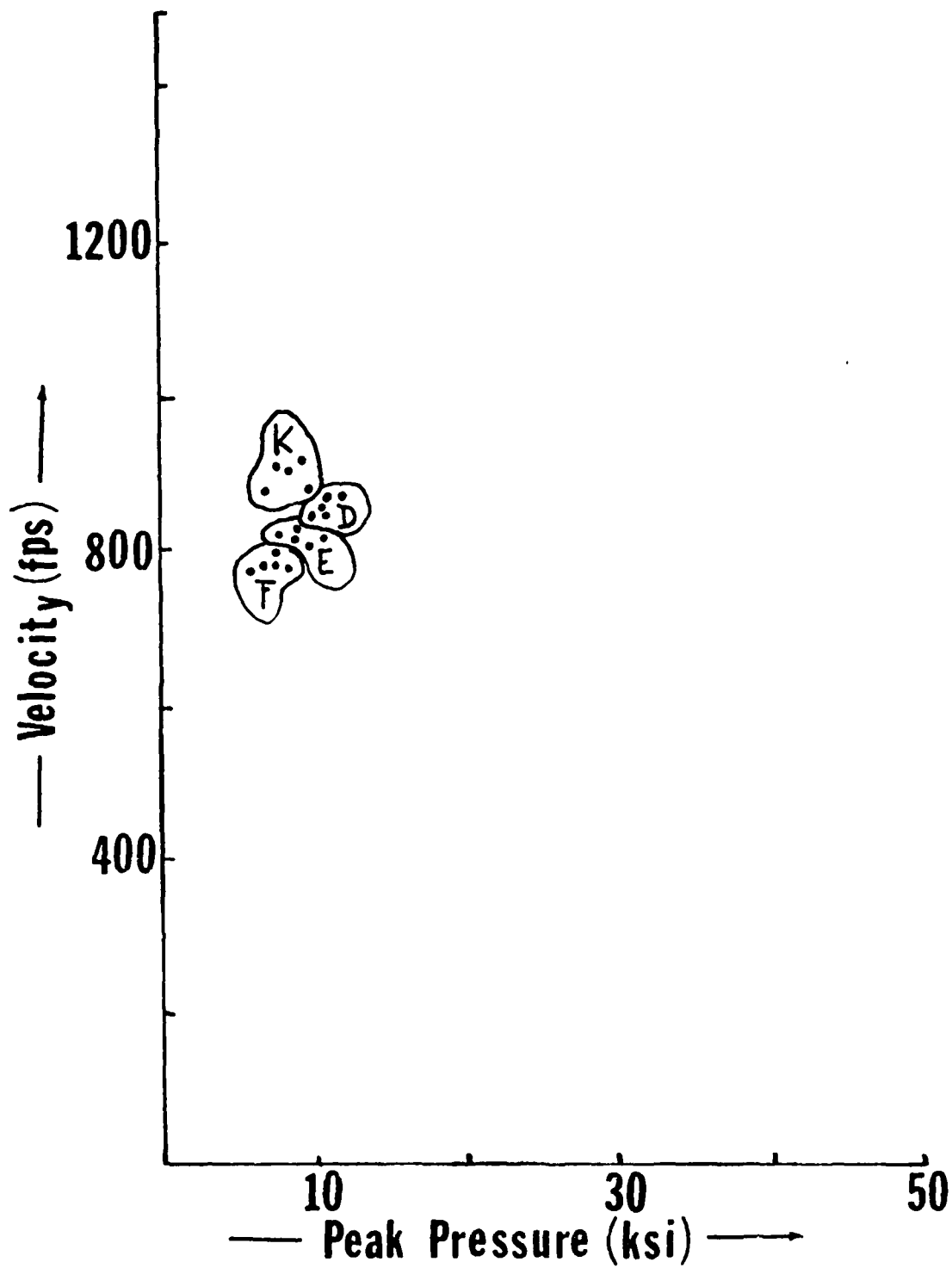


Figure 2. Pressure vs. Velocity for Some Commercial .38 Special Ammunition.

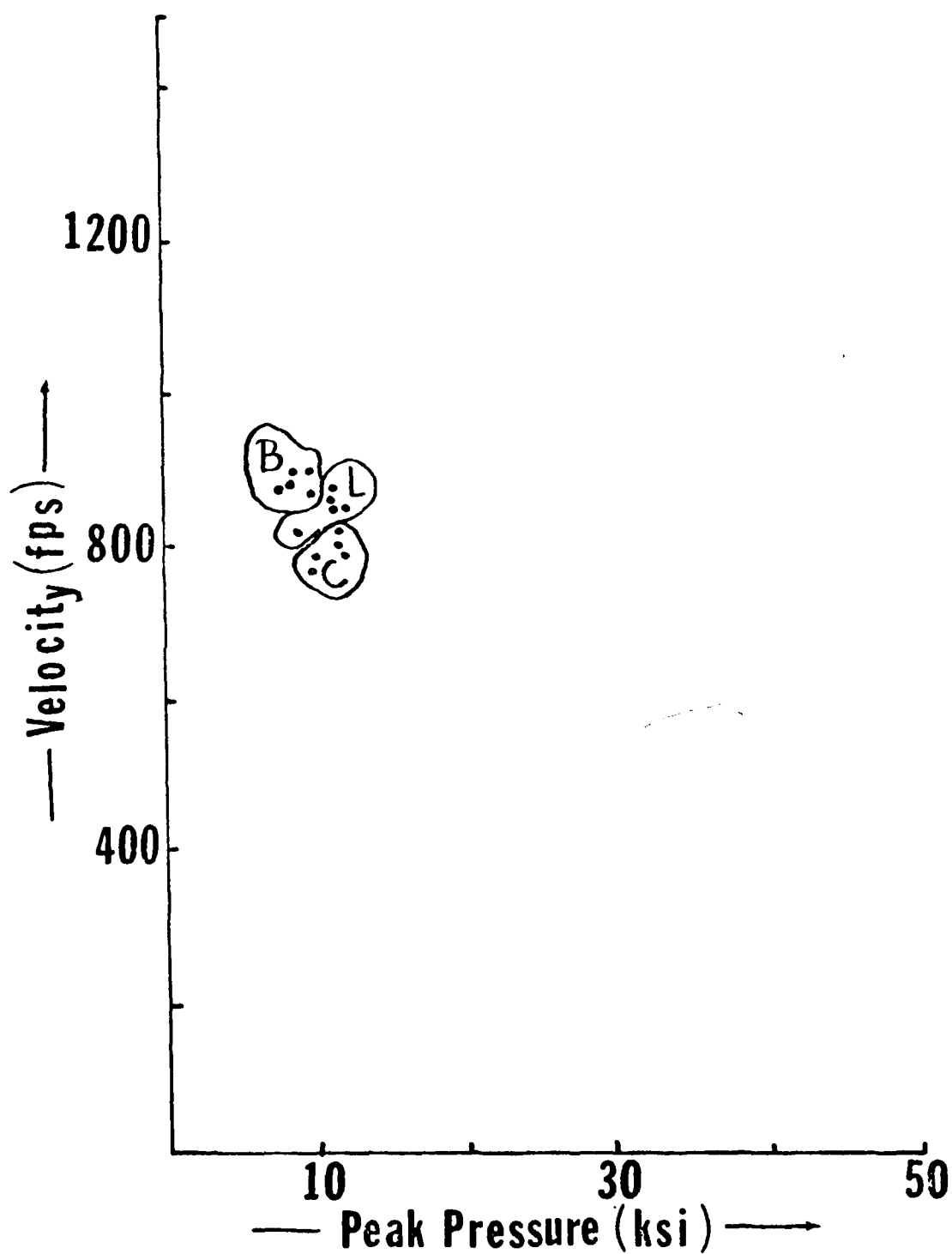


Figure 3. Pressure vs. Velocity for Some Commercial .38 Special Ammunition.

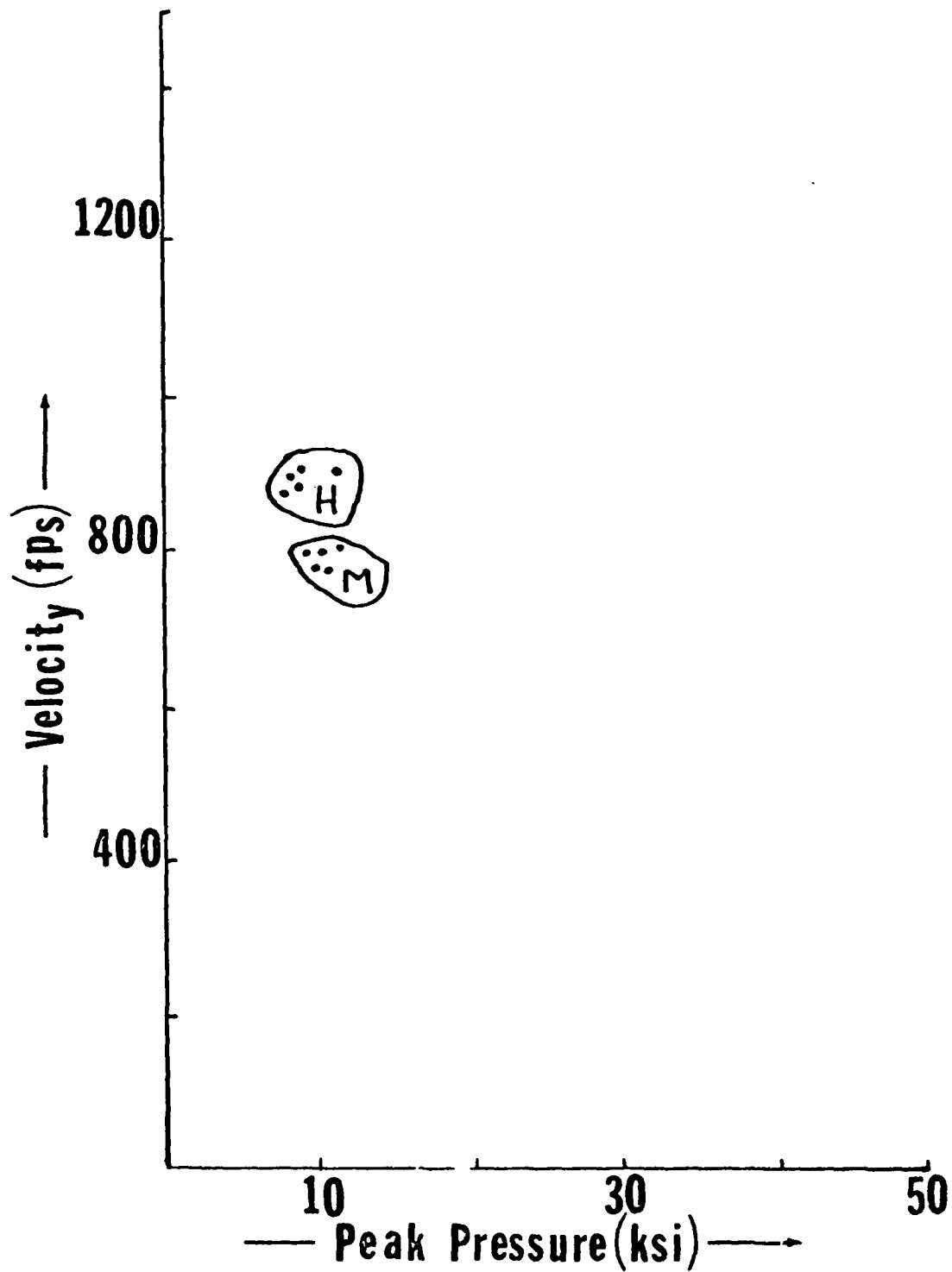


Figure 4. Pressure vs. Velocity for Some Commercial .38 Special Ammunition.

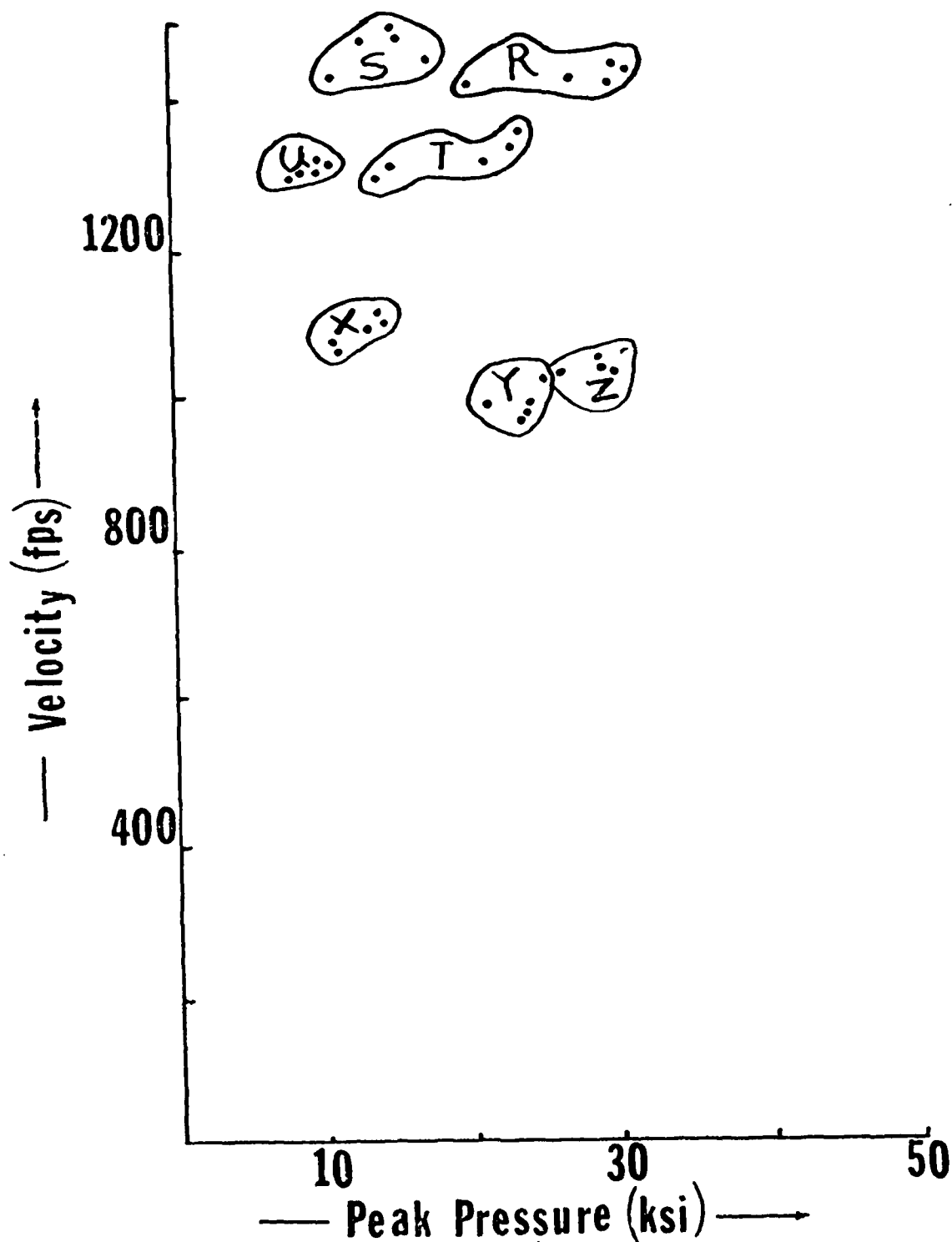


Figure 5. Pressure vs. Velocity for Some Commercial .38 Special "+P" Ammunition.

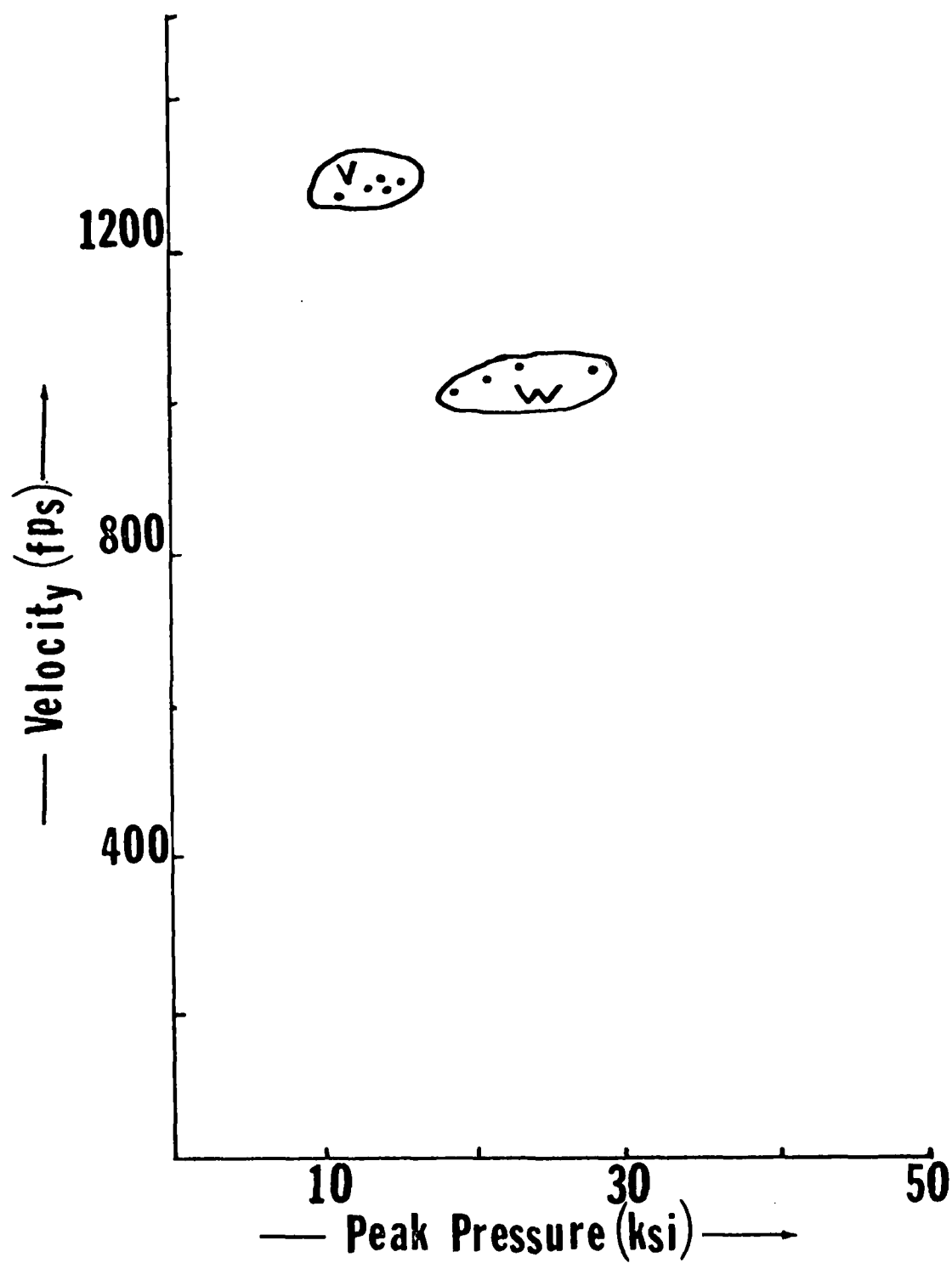


Figure 6. Pressure vs. Velocity for Some Commercial .38 Special "+P" Ammunition.

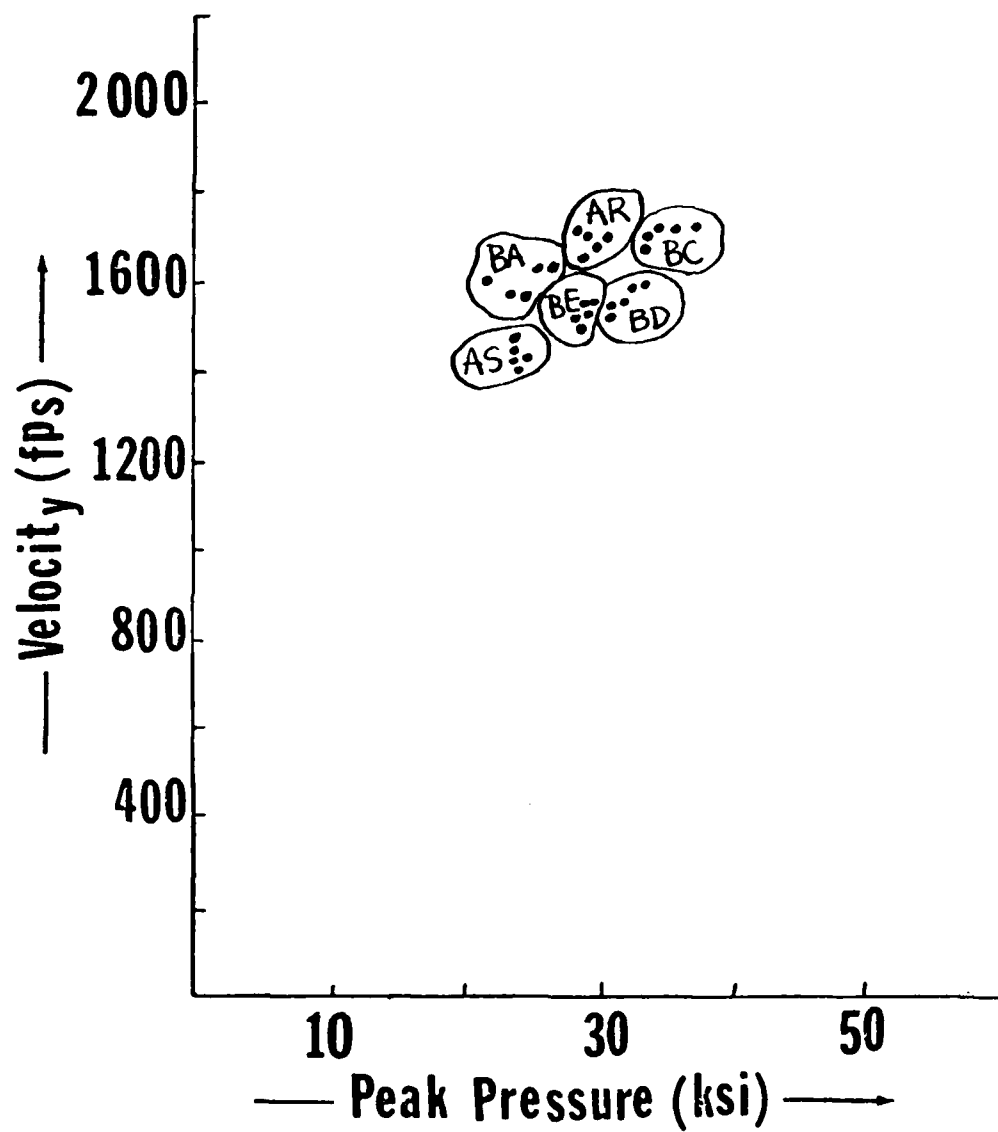


Figure 7. Pressure vs. Velocity for Some Commercial .357 Magnum Ammunition.

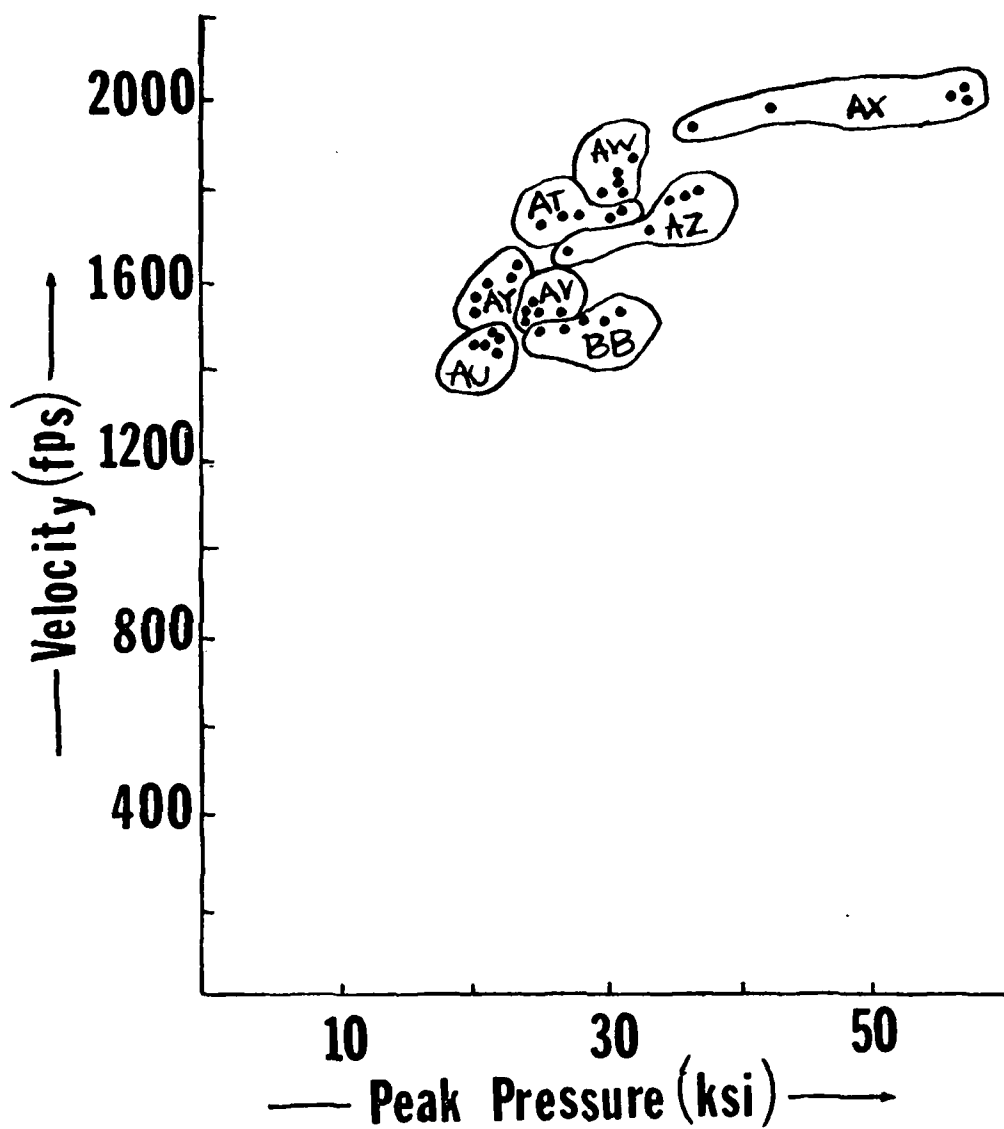


Figure 8. Pressure vs. Velocity for Some Commercial .357 Magnum Ammunition.

TABLE I

IDENTIFICATION OF CODE LETTERS IN FIGURES 1 THRU 8

.38 SPECIAL

<u>Code Letters</u>	<u>Ammunition</u>
B	Winchester-Western 158-grain lead round-nose
C	Winchester-Western 148-grain wad cutter
D	Remington 148-grain wad cutter
E	Federal 38 Special Match 148-grain wad cutter
F	Speer 148-grain wad cutter
G	Smith and Wesson 148-grain wad cutter
H	Remington 158-grain lead round-nose
I	Winchester-Western 200-grain lead round-nose
J	Smith and Wesson 158-grain lead round-nose
K	Speer 158-grain lead round-nose
L	Speer 200-grain lead round-nose
M	Remington 200-grain lead round-nose
N	Speer 110-grain jacketed hollowpoint
O	Remington 125-grain jacketed hollowpoint
P	KTW 105-grain Metal Piercing
Q	Super Vel 110-grain jacketed soft point

.38 Special "+P"

R	Smith and Wesson "+P" 90-grain jacketed soft point
S	Remington "+P" 95-grain jacketed hollowpoint
T	Smith and Wesson "+P" 110-grain jacketed hollowpoint
U	Speer "+P" 125-grain jacketed hollowpoint
V	Speer "+P" 140-grain jacketed hollowpoint
W	Smith and Wesson "+P" 158-grain semi-wad cutter
X	Federal "+P" 158-grain lead round-nose
Y	Smith and Wesson "+P" 158-grain jacketed soft point
Z	Smith and Wesson "+P" 158-grain jacketed hollowpoint

.357 Magnum

AR	Speer 140-grain jacketed hollowpoint
AS	Smith and Wesson 158-grain jacketed soft point
AT	Smith and Wesson 110-grain jacketed hollowpoint
AU	Remington 158-grain semi-wad cutter
AV	Remington 158-grain lead round-nose
AW	Speer 125-grain jacketed hollowpoint
AX	KTW 90-grain Metal Piercing
AY	Speer 110-grain jacketed hollowpoint
AZ	Smith and Wesson 110-grain jacketed hollowpoint
BA	Winchester-Western 110-grain jacketed hollowpoint
BB	Winchester-Western 158-grain Lubaloy
EC	Smith and Wesson 125-grain jacketed hollowpoint
BD	Speer 158-grain jacketed soft point
BE	Federal 158-grain jacketed soft point

selected for the best representative of the high-pressure extreme because 1) it has the highest average pressure (29.1 ksi), 2) 158-grain was the most widely chosen bullet weight in section 2.3, and 3) hollowpoint was next most popular to lead round-nose in section 2.3. An interesting point is the comparison between "Z" and the .357 magnum ammunition shown in Figures 7 and 8. Note that the scales are different in Figures 7 and 8. More than half the .357 magnum loads have maximum peak pressures, minimum peak pressures, and average peak pressures less than the .38 Special "+P" load we selected ("Z"). These lower pressure .357 magnum loads are "AS", "AT", "AU", "AV", "AY", "BA", "BB" and "BE". "AR" is almost the same as "Z" with respect to pressure. The remaining five ("AW", "AX", "AZ", "BC" and "BD") run from a maximum pressure of 32.0 ksi ("AW") to 57.0 ksi ("AX").

e. Summary of the Analysis.

- A. The Colt Model D5540 Diamondback and the Smith and Wesson Model 15-3, .38 caliber, with 4-inch barrels would be a most representative choice of handguns to examine and compare in detail.
- B. Remington 158-grain lead round-nose .38 Special and Smith and Wesson 158-grain jacketed hollowpoint "+P" .38 Special would be a most representative choice of low-pressure and high-pressure extremes of ammunition to compare.
- C. Attention will be focussed on deformation in the recoil plate and the effect of peak pressures on the cylinders.
- D. A relatively low number of rounds need be fired in each gun. One each Colt and Smith and Wesson will be fired with fifty rounds of high-pressure ammunition, and one each Colt and Smith and Wesson will be fired with fifty rounds of low-pressure ammunition.

III. EXPERIMENTAL APPROACH AND RESULTS

a. Static Pressure Measurements on the Cylinders.

One of the tests was to provide a static internal hydrostatic pressure on a single chamber of a revolver cylinder comparable to the peak pressure the chamber would see when firing type "Z" ammunition (Smith and Wesson 158-grain jacketed hollowpoint "+P" .38 Special), and to then measure resulting strains at various locations on the cylinder. The type "Z" ammunition had a maximum measured peak pressure of 31 ksi. The chamber to be pressurized was plugged at the "rear" with an empty .357 cartridge case sawed off to about 3/8-inch height. The chamber was then filled with stearic acid (USP) powder which in turn was compressed with a .348 push rod of tool steel inserted from the "front" of the cylinder. The stearic acid behaves much like a wax, and cannot support a shear load, thus guaranteeing the push rod will transmit its load so as to create a pure hydrostatic load within the chamber.

To create a 31,000 psi pressure, the .348-inch piston required a 2,950-pound load, which was provided by a hydraulic press. The load could be held for as long a period as necessary. (The typical experiment took 15-20 minutes to record all the data.) The "fit-up" of the piston was such that no stearic acid was extruded out of the chamber. Before testing, six strain gages each were mounted on both the Colt Model D5540 and the Smith and Wesson Model 15-3 which were to fire the type "Z" ammunition.⁴ The gages were oriented to sense circumferential strain and were located centered over each chamber about 1/2 inch from the rear of the cylinder. They were spaced well away from the cylinder stop notches in the cylinder. It is worth noting that since these notches and their ramps are not symmetric, they can be expected to cause an asymmetry in the circumferential strain of the cylinder. The cylinder surfaces were prepared and the gages mounted using standard procedures. Measurements were made using a Vishay-Ellis Model 10 Strain Gage Bridge. "Zeroes" typically were found to be reproducible to within about 0.2% of the largest measured strain when compared before and after pressurizing the chamber. Re-pressurizing was found to provide essentially identical data. This observation means the strain gage bonding was reliable.

Care was taken to mark the chamber which had been pressurized, and this same chamber was used to fire each round during the firing tests. (It was also scanned with the Halec Detector described later in the interest of safety.) The cylinder was marked by removing the strain gage and the bluing, which facilitated examination of the surface with the Halec Detector. After all fifty rounds had been fired in the gun, a new strain gage was fastened to the one chamber which had been marked. (All the other gages survived the firings,

⁴ Micro-Measurements Series CEA-06-125UW-120 Strain Gages.

and, indeed, for the Colt they still had the same zero readings.⁵⁾ The static pressure testing was repeated for the "fired" guns. Table II summarizes the results:

TABLE II
STRAIN MEASUREMENTS BEFORE AND AFTER FIRING

Chamber	Colt		Smith and Wesson	
	Before Firing	After Firing	Before Firing	After Firing
Pressurized	2766 $\mu\epsilon$ *	2766 $\mu\epsilon$ *	2249 $\mu\epsilon$ *	2519 $\mu\epsilon$ *
#2	172	209	143	119
#3	124	85	124	106
#4	39	42	39	26
#5	- 33	- 27	- 138	- 34
#6	- 236	- 261	- 237	- 235

* $\mu\epsilon$ = microstrain = 10^{-6} inches/inch.

The other chambers are listed in order clockwise from the pressurized chamber as viewed from the rear of the gun. Figures 9 and 10 are plots of this data where the cylinder is again viewed from the rear of the gun. Again the "zero" readings on the strain gages were reproducible upon releasing pressure.

b. Eddy Current Detector Measurements on Recoil Plates.

One of the early damage sites postulated for the handguns is the recoil plate. These plates are of different design in the Colt and the Smith and Wesson guns, although each of them is essentially a circular plate with a small hole in the center to receive the firing pin. (See Figure 11.) The Colt recoil plate is made from AISI Type 01 oil hardening tool steel with a Rockwell "C" hardness of 48-52. The Smith and Wesson recoil plate (called a hammer nose bushing by Smith and Wesson) is made from SAE 1065-1080 carbon steel with a Rockwell "C" hardness of 45-50.⁶

⁵ We were unable to compare gage zero readings before and after firing the Smith and Wesson because of a change in the bias or "balance" voltage setting of the strain gage bridge during the intervening period.

⁶ We wish to express our appreciation to Mr. Harold Waterman of Colt Industries and Mr. H. E. Sibley of Smith and Wesson for this information as well as samples of their recoil plates (or hammer nose bushings).

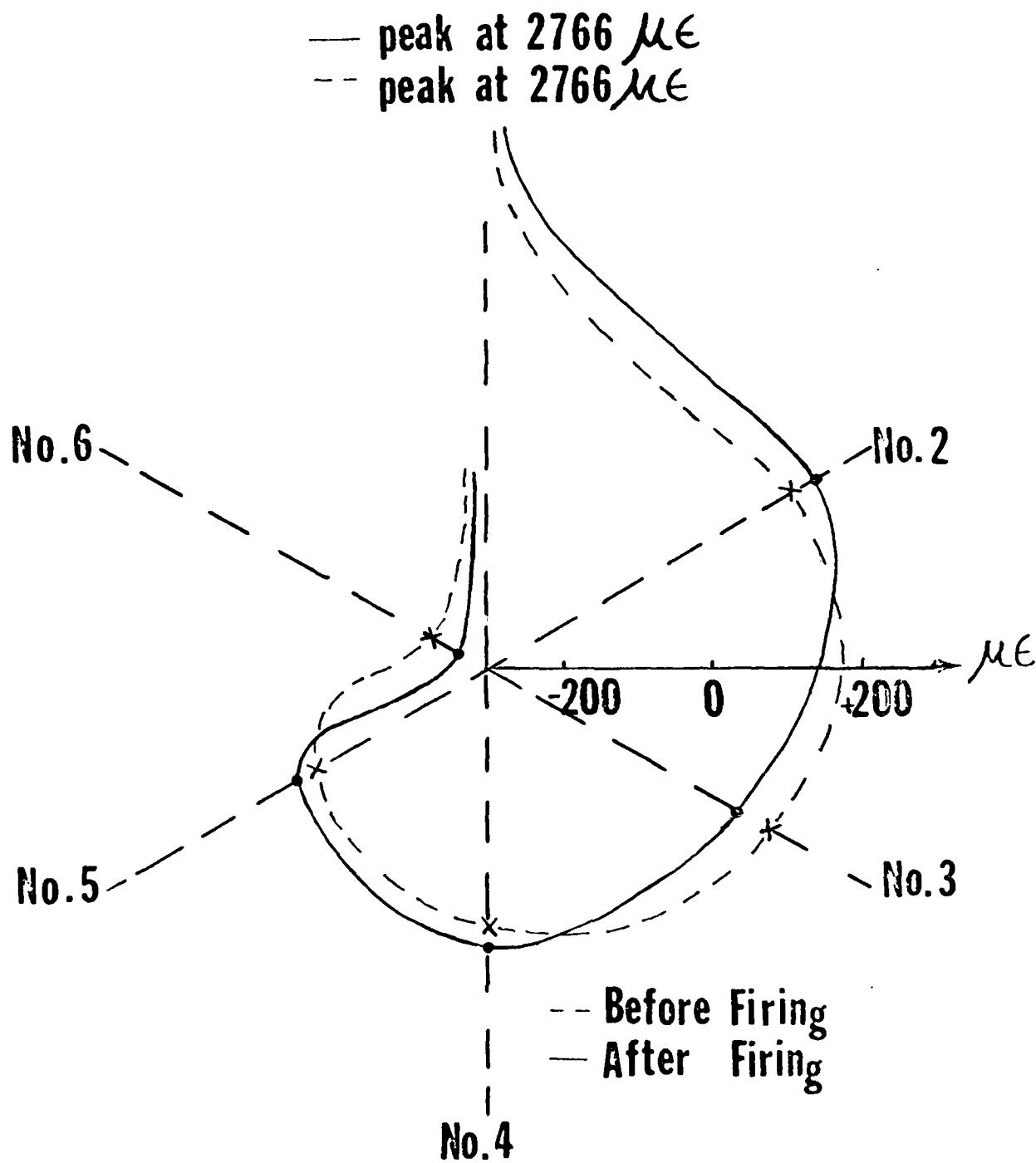


Figure 9. Strain Measurements on Statically Pressurized Colt Cylinder.

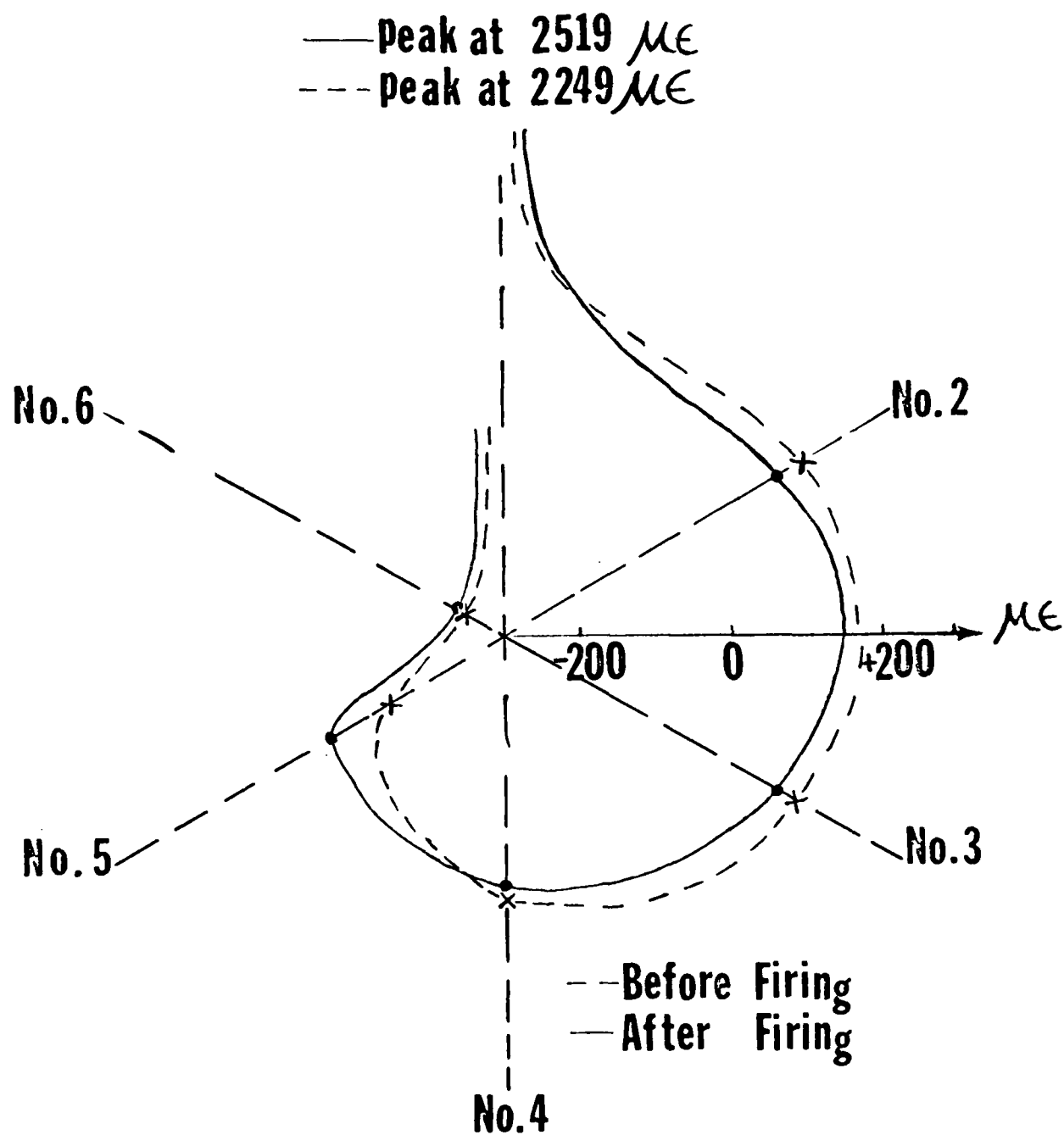
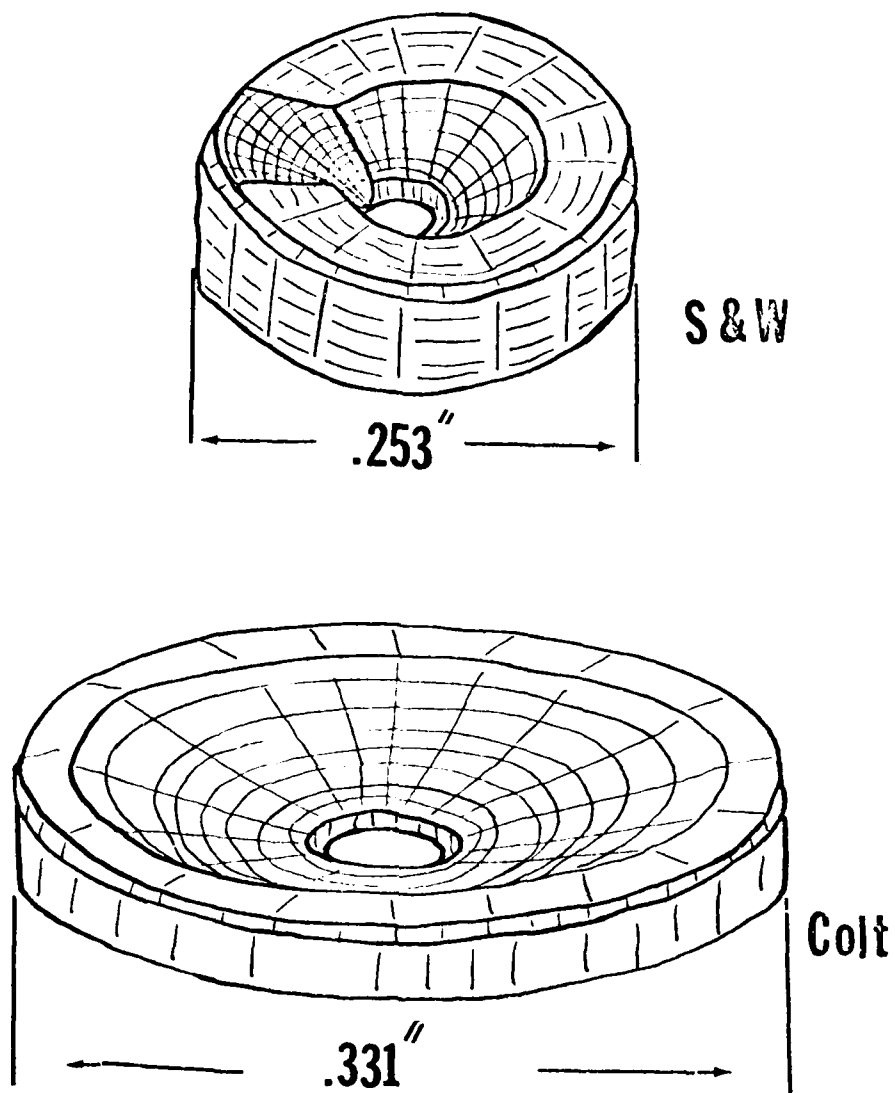


Figure 10. Strain Measurements on Statically Pressurized Smith and Wesson Cylinder.



(Not to scale)

Figure 11. Sketch of Colt and S & W Recoil Plates

The problem was to find some method of inspection which could be used in addition to visual observations, which would be non-destructive, and which could detect any progressive damage of the part. The extremely small size of the recoil plates (1/4-inch to 3/8-inch diameter) does not allow the use of the conventional techniques such as ultrasonic attenuation.

Considerable time was spent endeavoring to adapt a four point probe, conductivity measuring technique to evaluate surface damage of the recoil plates, but the small size and asymmetric design of the plates did not allow a convenient solution by this technique. This investigation was abandoned in favor of an electromagnetic sensing technique which is made possible by use of the Halec Crack Detector. This instrument is an eddy current crack detector manufactured by Hacking Associates (Electronics) Ltd., New Barnes Mill, St. Albans, Hartfordshire, United Kingdom. They identify it as their Mark 1, Type C. Eddy current inspection is based on the principles of electromagnetic induction and can be used to measure electrical conductivity, magnetic permeability, grain size, state of heat treatment, and hardness, among other properties.

This instrument is sufficiently sensitive to detect changes in steel produced by very limited plastic deformation. This is illustrated in the calibration curves (Figure 12 and Figure 13) which were developed on specimen of steel 1/4-inch diameter and 3/16-inch thick of the respective compositions and hardnesses specified for the Colt and Smith and Wesson recoil plates. These small blanks were placed in a heat-treated closed die set wherein a hardened convex rounded rod was driven into the blank by a sharp blow from a 2-pound hammer. After every five blows, readings were taken across the circular face of the specimen (which now contains a small dimple from the convex punch). Characteristically the Halec reads "0" at or very near an edge and has its highest value at the very center of the blank. These maximum readings are plotted in Figures 12 and 13.

In both of these calibration tests the blank began to plastically deform on the first blow, and after 160 blows the Smith and Wesson material had sufficiently deformed to make it difficult to remove it from the die set. This limiting deformation was reached earlier (40 blows) in the Colt material. This more rapid plastic deformation of the material as a function of blows could be due to the material itself. However, a different person was effecting the hammer blows in the two cases and the early limiting deformation in the Colt material is deemed to come from this probable variation in impulse level. This is most likely since in our simulated recoil plates, the Colt had a Rockwell "C" hardness of 51.2 and the Smith and Wesson had a Rockwell "C" hardness of 47.5, so the Colt material should not deform as readily in the test.

It should be noted that Figure 12 for the Colt material represents only fifty blows whereas the Smith and Wesson plot (Figure 13) represents 190 blows. The data for the two materials is very characteristic for the first fifty blows. The limiting value of 100 indicates the limit of the instrument (without resetting) although there will be some damage limit for the blank due to the die constraint, i.e., when the material completely fills the die it can no longer flow plastically.

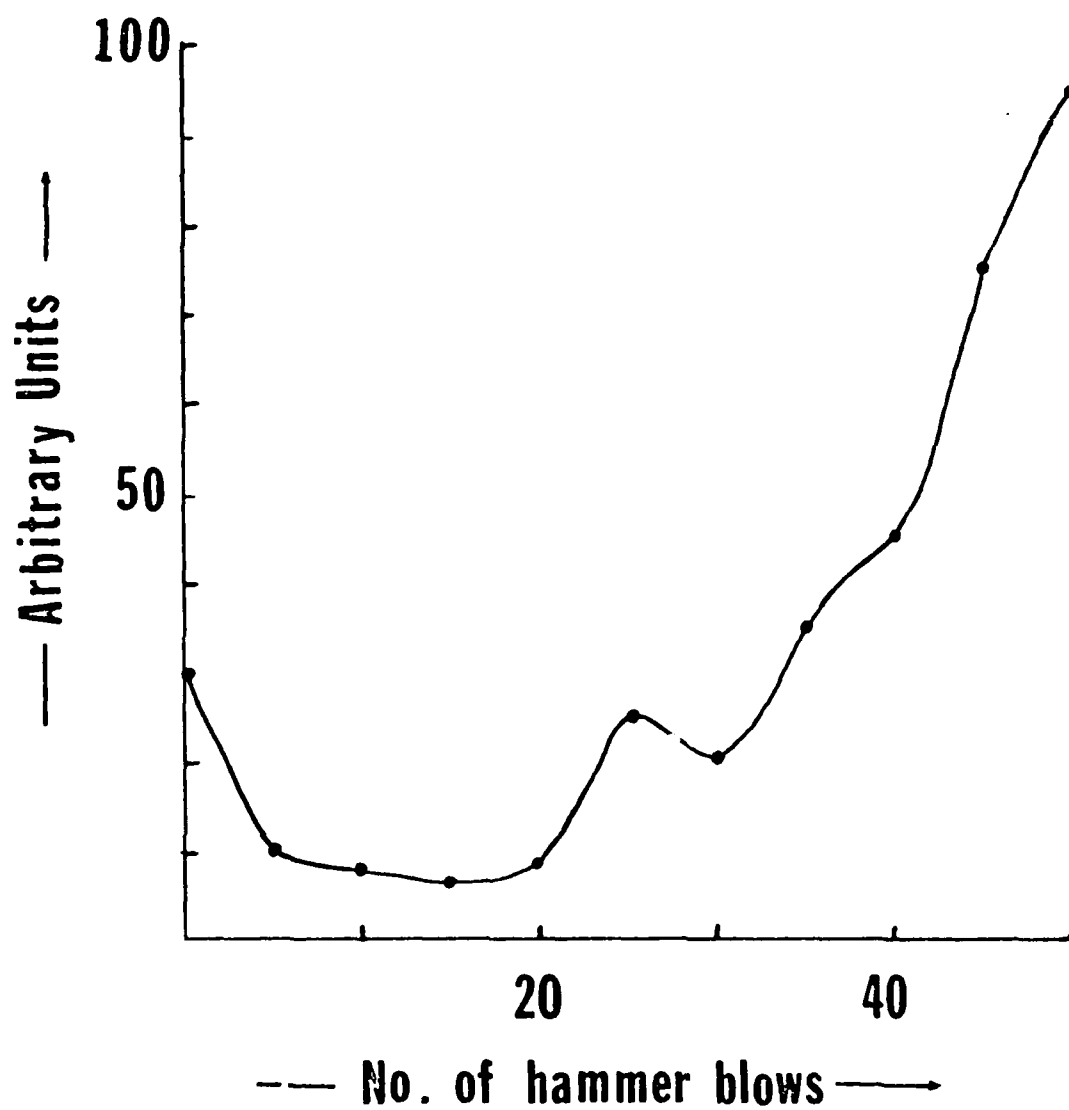


Figure 12. Detector Output vs. Number of Hammer Blows on Simulated Colt Recoil Plate.

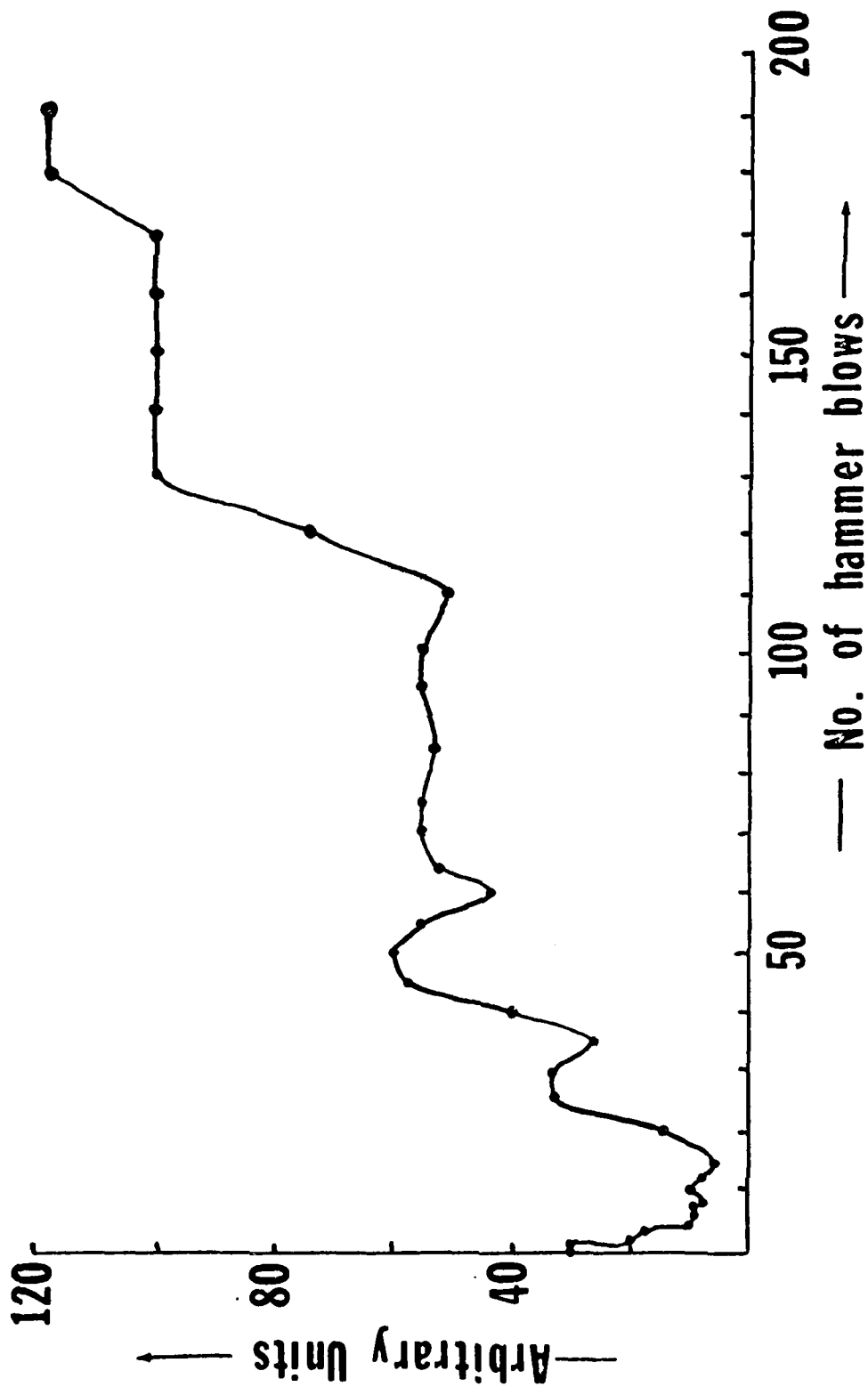


Figure 13. Detector Output vs. Number of Hammer Blows on Simulated Smith and Wesson Recoil Plate.

To demonstrate that the Halec instrument was still capable of detecting plastic deformation damage at this point, the instrument was reset at a new zero at 170 blows and the test continued through 190 blows. The indicated increase in reading was added to the original values for convenience of plotting.

After each gun was fired five times with its prescribed ammunition, its recoil plate was scanned with the Halec instrument. This scan was carried out in the paths which were orthogonal to each other (one being athwart in the gun). Since the recoil plates are maintained in place by upsetting the frame metal around them, the edge of the recoil plate abuts tightly against the frame and this appears to the Halec instrument as a crack thereby yielding a high reading. When the probe of the instrument reached the center of the recoil plate, it dropped into the firing pin hole causing the coil to become saturated and giving a high reading. The area of concern thereby became the area between the firing pin hole and the periphery of the recoil plate. Plots of values as a function of the number of firings are presented in Figure 14 for the athwart scan and Figure 15 for the vertical scan of the Colt using low-pressure ammunition. The data resulting from using high-pressure ammunition in the Colt are presented in Figure 16 for athwart scan and Figure 17 for vertical scan. Similar plots of the scan data for the Smith and Wesson are found in Figure 18 athwart scan, Figure 19 vertical scan for high-pressure ammunition and Figure 20 athwart scan and Figure 21 vertical scan for low-pressure ammunition.

c. Observations on Recoil Plates, Firing Pins, and Cylinders.

It is of interest to note the flow pattern in and around the recoil plate. The recoil plate, insitu, for the Smith and Wesson after fifty firings is shown in Figure 22 (low-pressure ammunition) and Figure 23 (high-pressure ammunition). There is a slight deformation ring formed by the periphery of the cartridge case rim which can be observed by eye. There is only a slight observable deformation on the edge of the firing pin hole. The light cross in these figures is the result of the Halec probe scan.

The recoil plate, insitu, for the Colt after fifty firings is shown in Figure 24 (low-pressure ammunition) and Figure 25 (high-pressure ammunition). In this case, the deformation produced by the cartridge rim is masked by the deformation marks produced when the plate was crimped into the frame.

Close examination of the firing pins showed unexpected asymmetry. Both Colt and Smith and Wesson firing pins tended to be flat on one side of the pin and roughly rounded on the other side. The flat side could be either to the left or the right. The Colt appears to be the most smoothly tapered and the most symmetric of the two. The Smith and Wesson looks as though the rounding operation was done free-hand.

After the strain measurements were completed on the cylinders of the Colt and Smith and Wesson which had fired high-pressure ammunition, the cylinders were sectioned, polished, and etched (in 3% Nital). They were sectioned in a plane orthogonal to their axes of rotation passing through the former locations of the strain gages. Figure 26 shows a photomicrograph (250X) of the Colt cylinder, and Figure 27 shows a photomicrograph of the Smith and Wesson cylinder (250X). Both were etched, then repolished, and

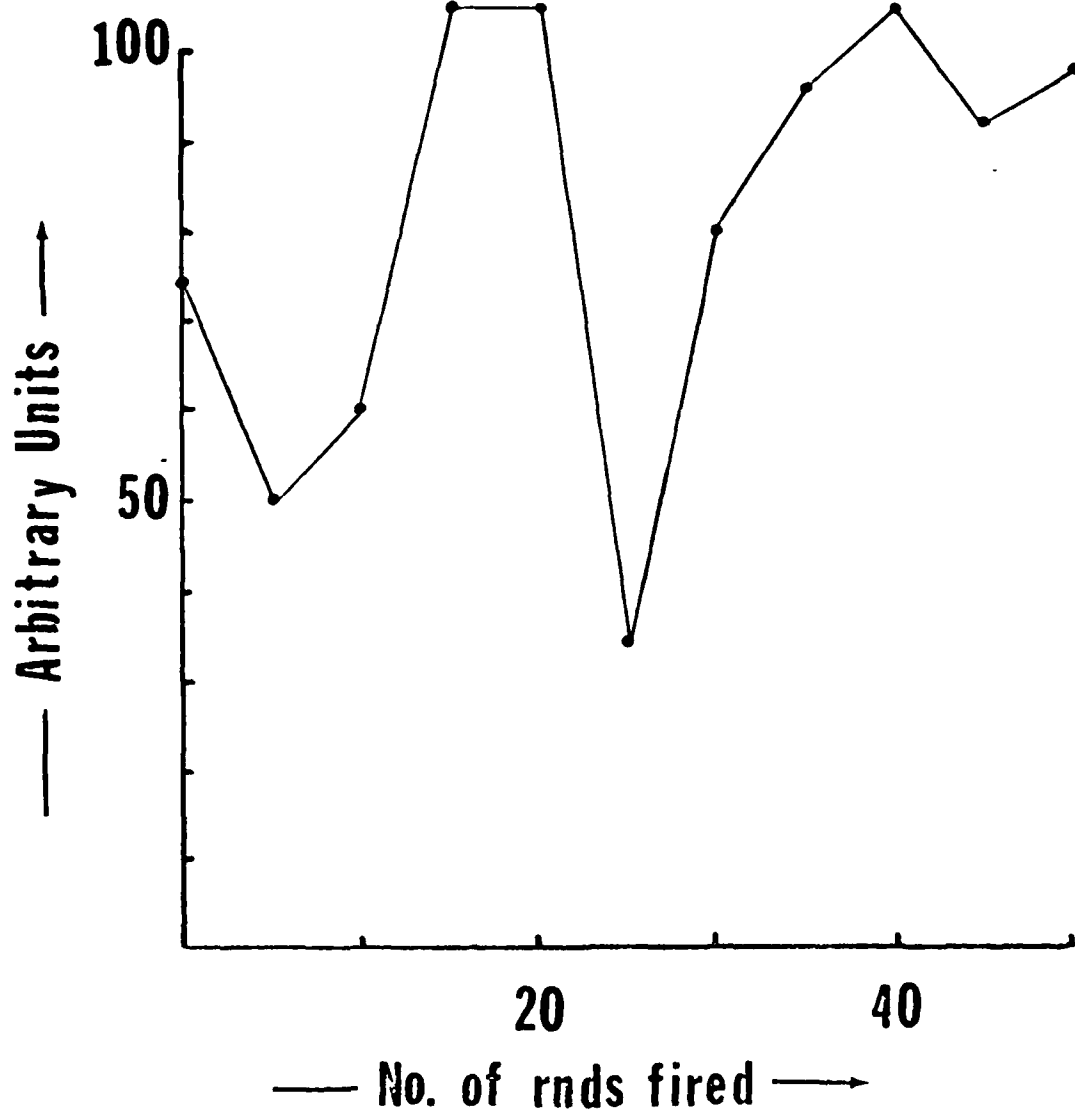


Figure 14. Detector Output vs. Number of Rounds Fired for Athwart Scan of Colt Using Remington Ammunition.

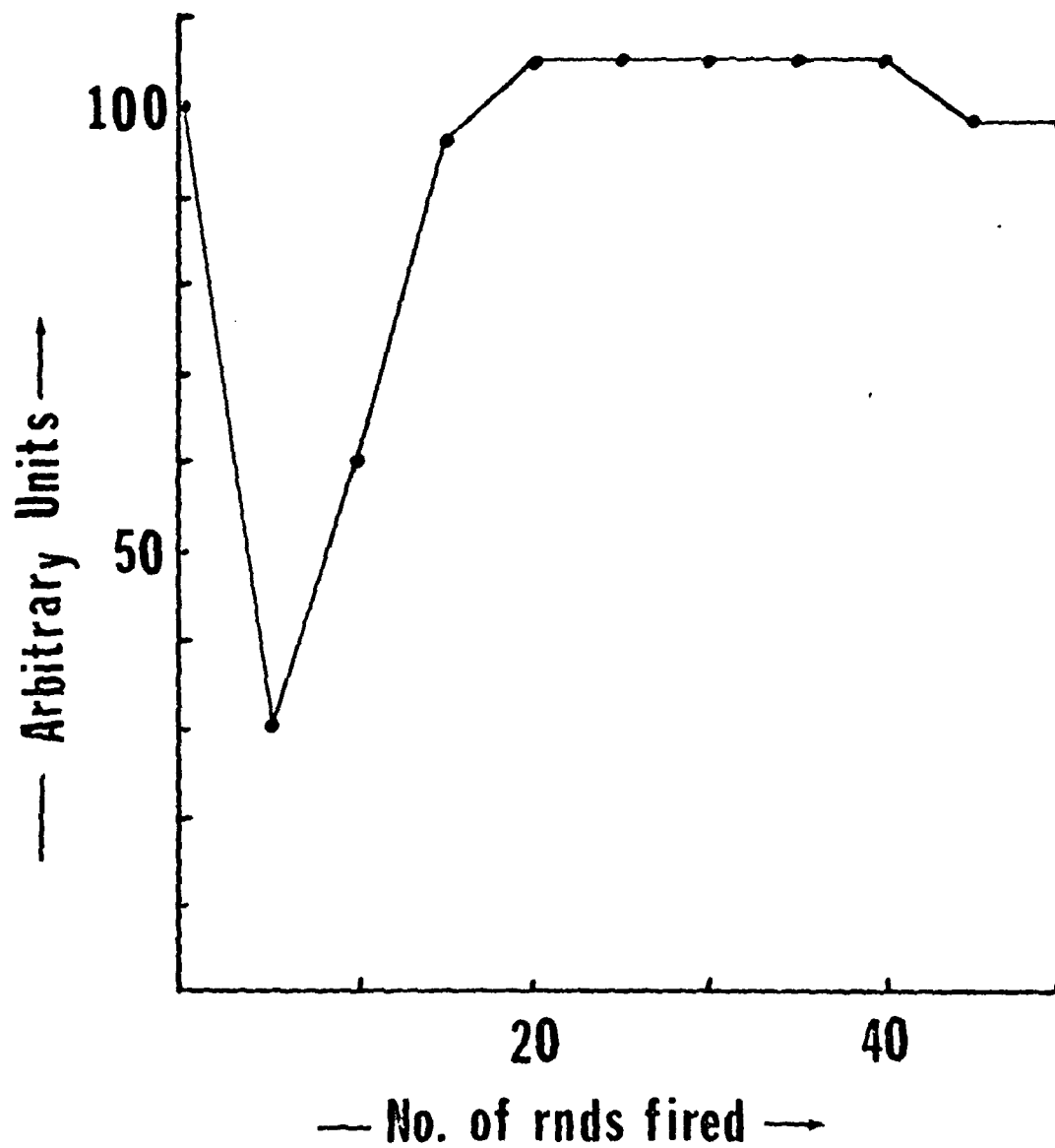


Figure 15. Detector Output vs. Number of Rounds Fired for Vertical Scan of Colt Using Remington Ammunition.

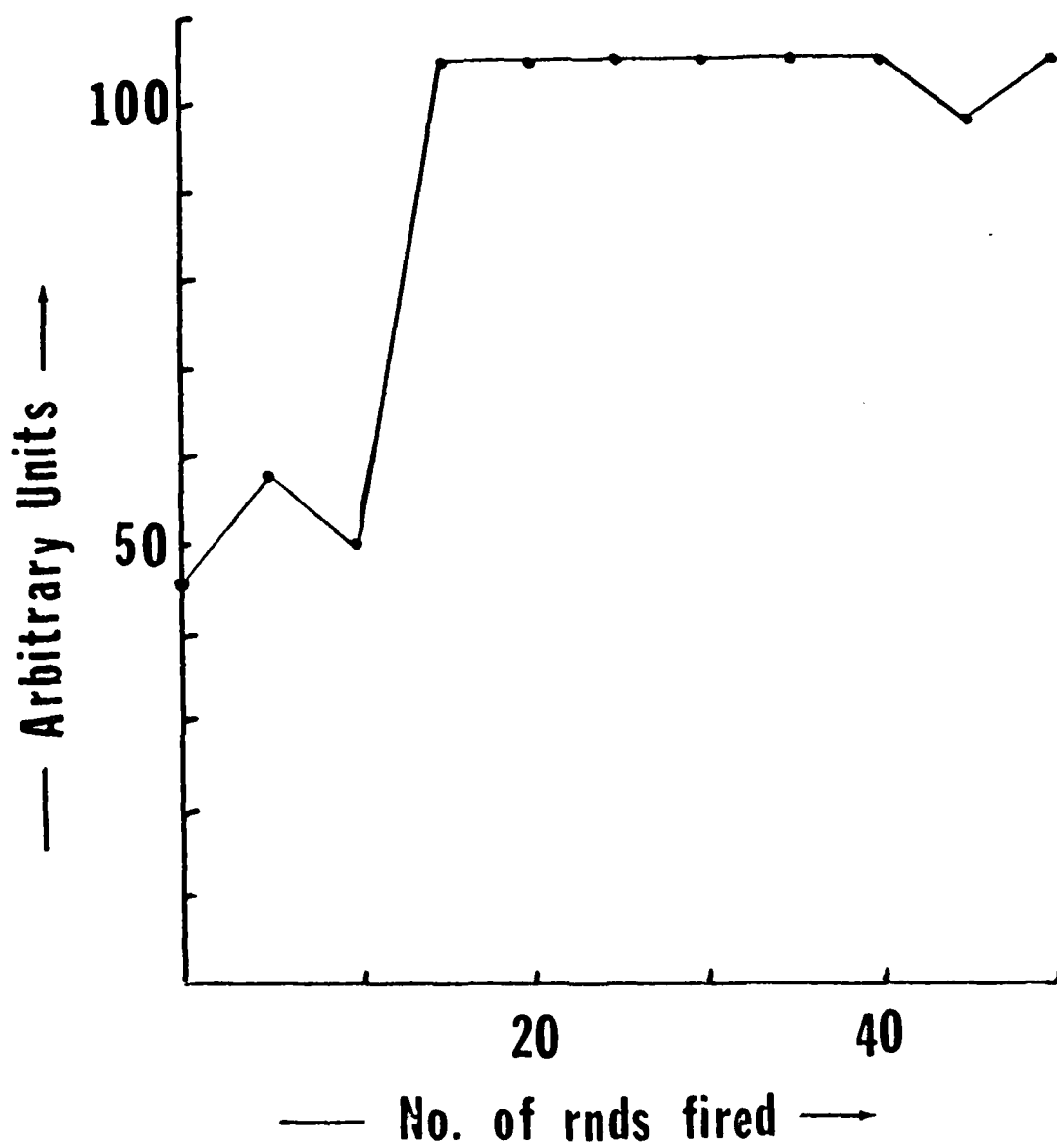


Figure 16. Detector Output vs. Number of Rounds Fired for
Athwart Scan of Colt Using Smith and Wesson Ammunition.

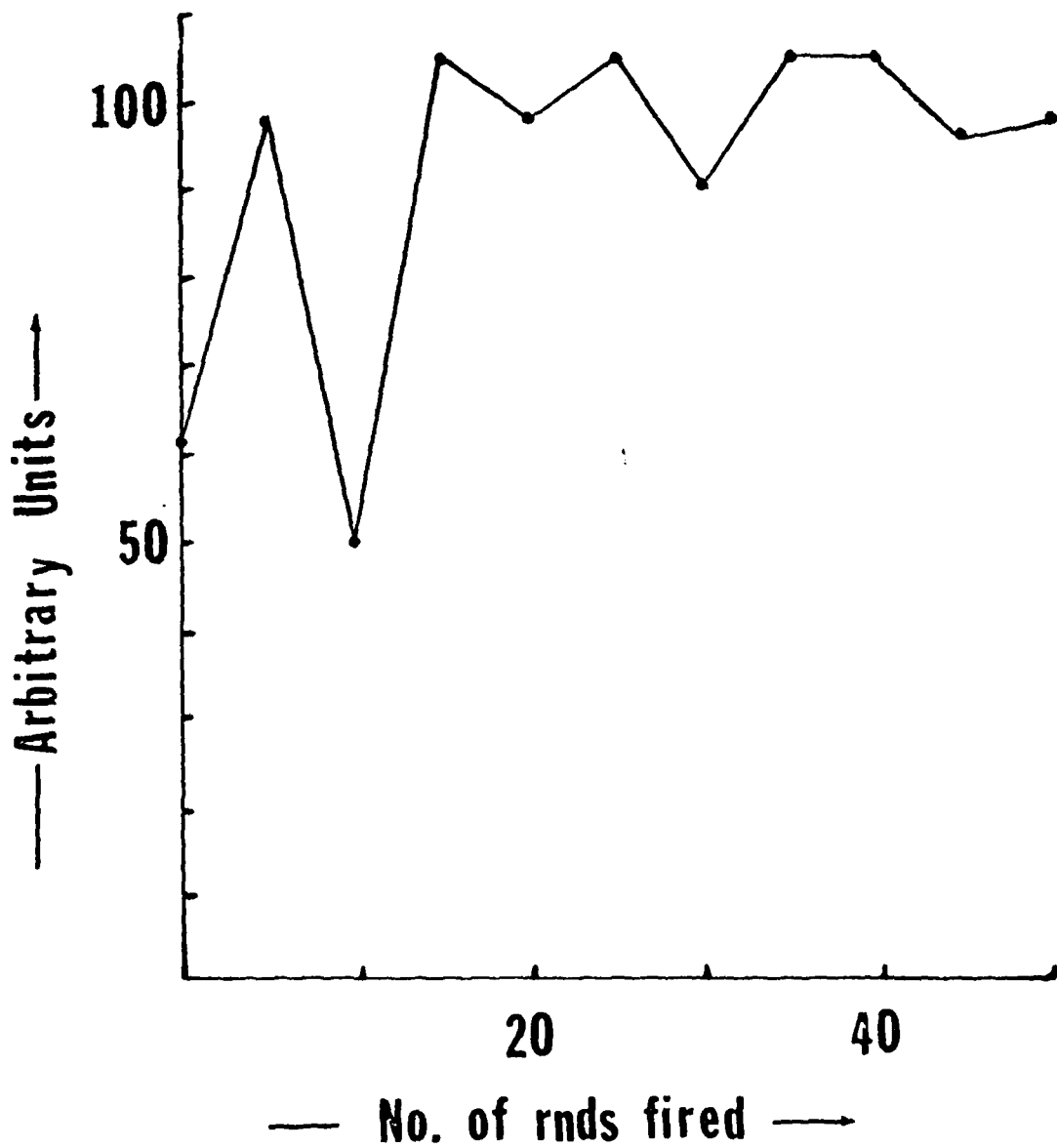


Figure 17. Detector Output vs. Number of Rounds Fired for Vertical Scan of Colt Using Smith and Wesson Ammunition.

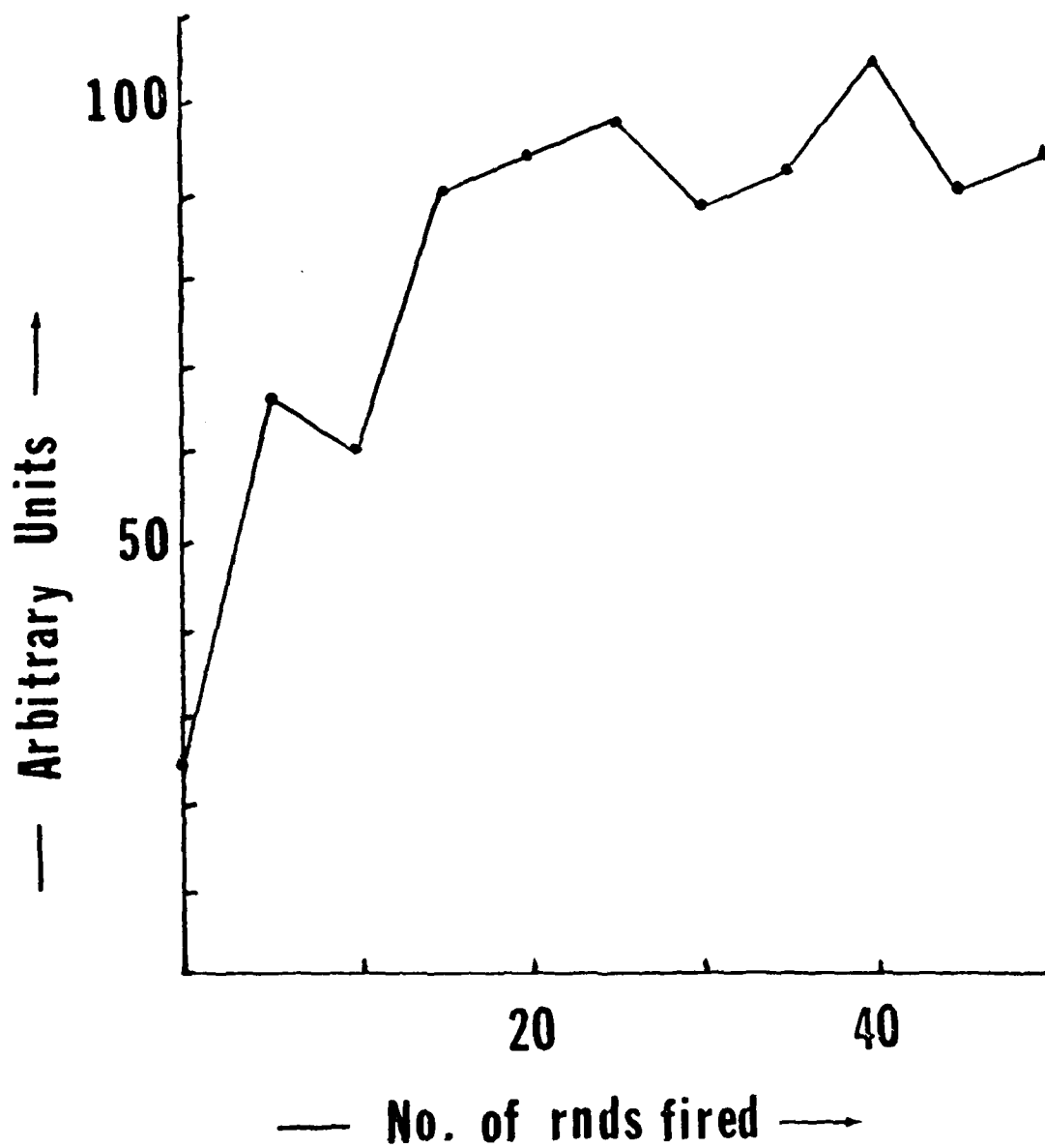


Figure 18. Detector Output vs. Number of Rounds Fired for Athwart Scan of Smith and Wesson Using Smith and Wesson Ammunition.

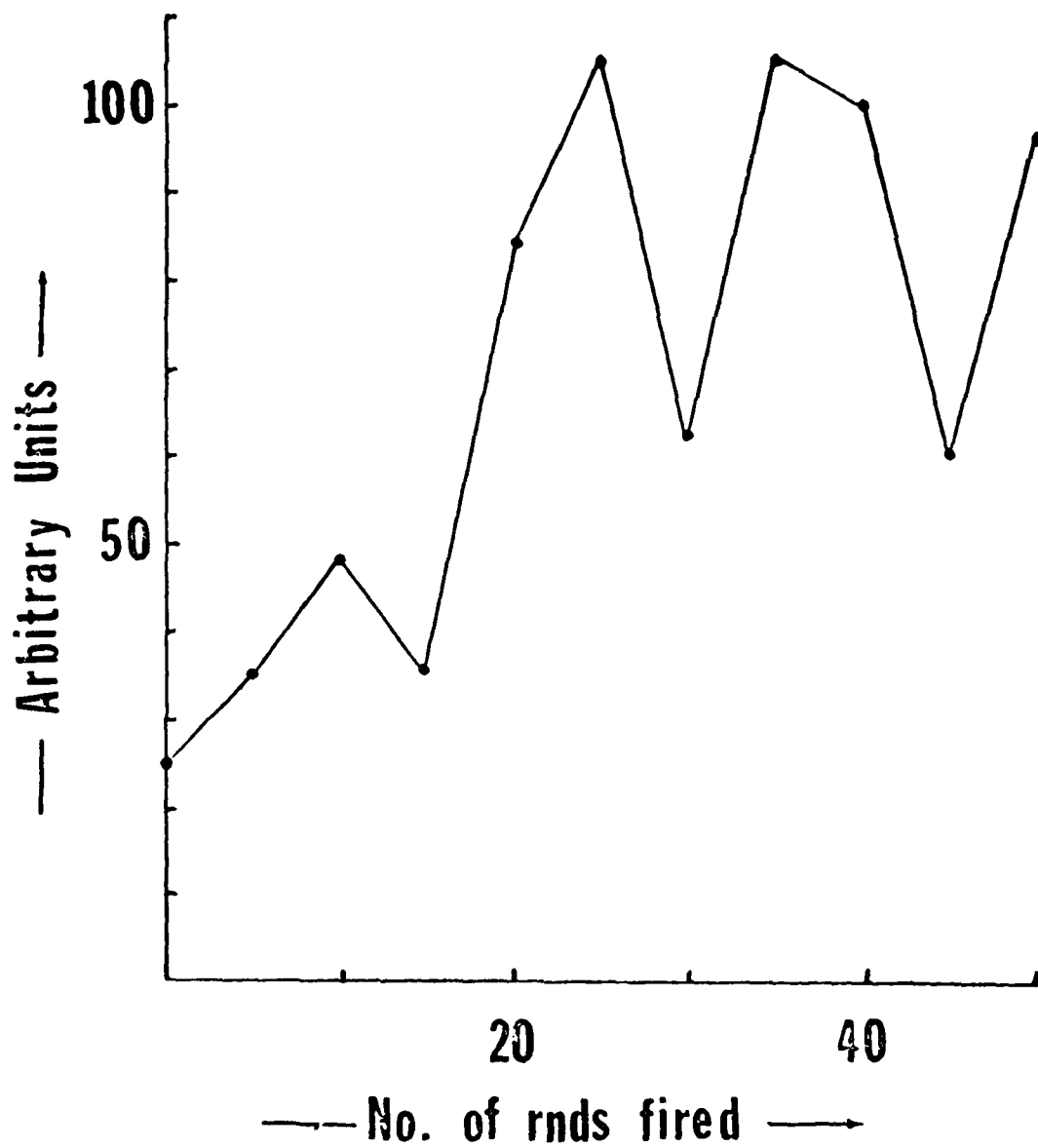


Figure 19. Detector Output vs. Number of Rounds Fired for Vertical Scan of Smith and Wesson Using Smith and Wesson Ammunition.

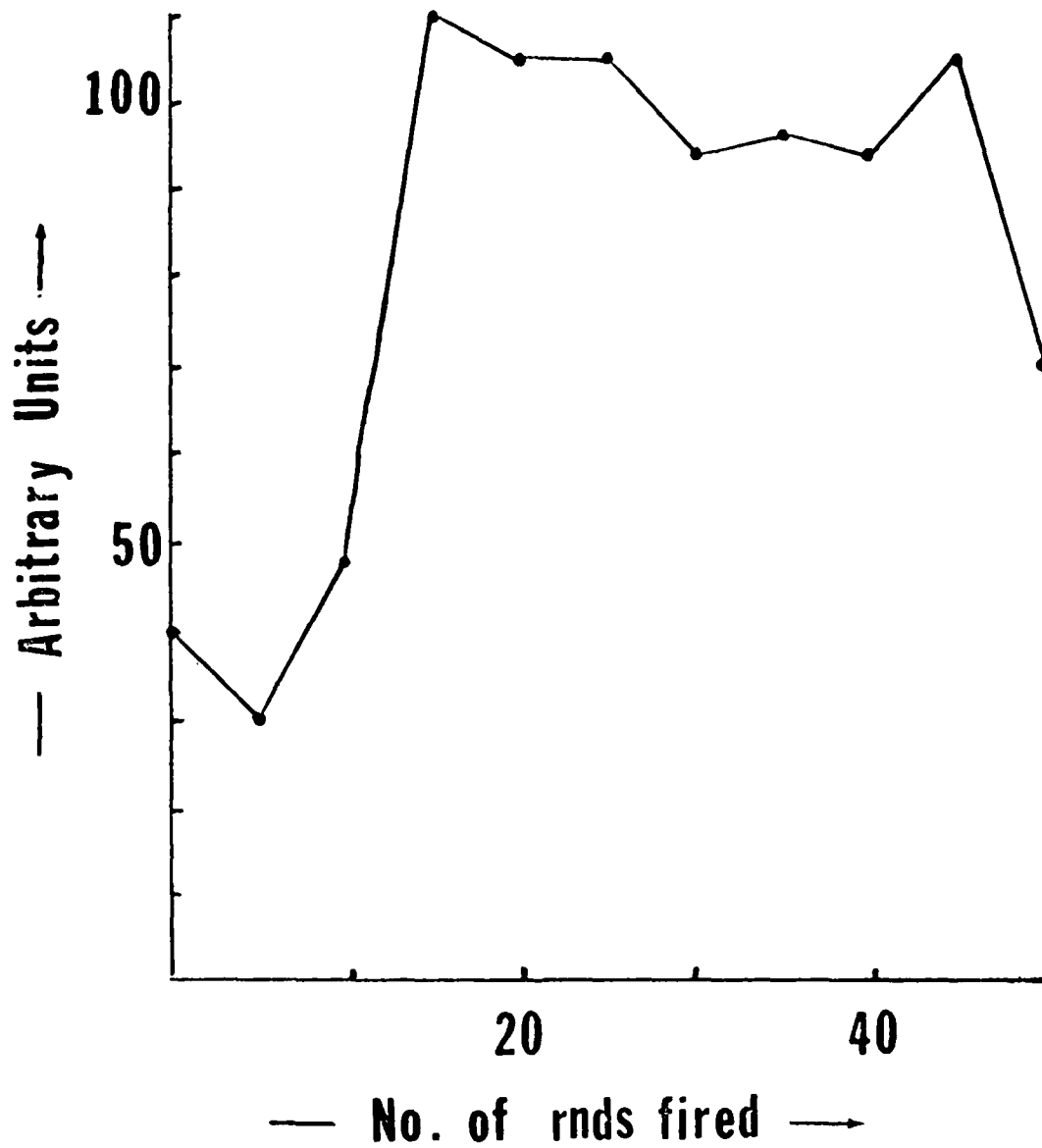


Figure 20. Detector Output vs. Number of Rounds Fired for Athwart Scan of Smith and Wesson Using Remington Ammunition.

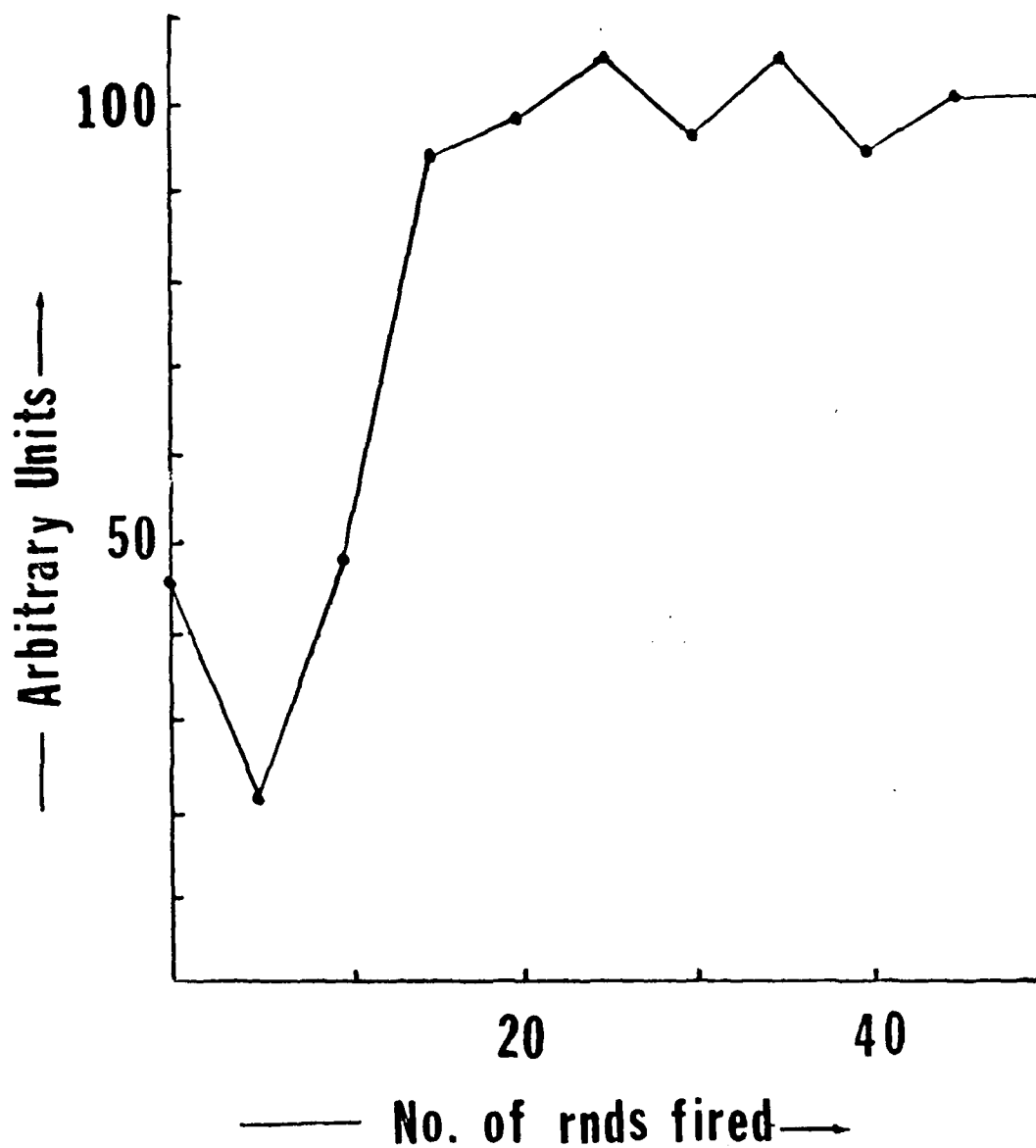


Figure 21. Detector Output vs. Number of Rounds Fired for Vertical Scan of Smith and Wesson Using Remington Ammunition.

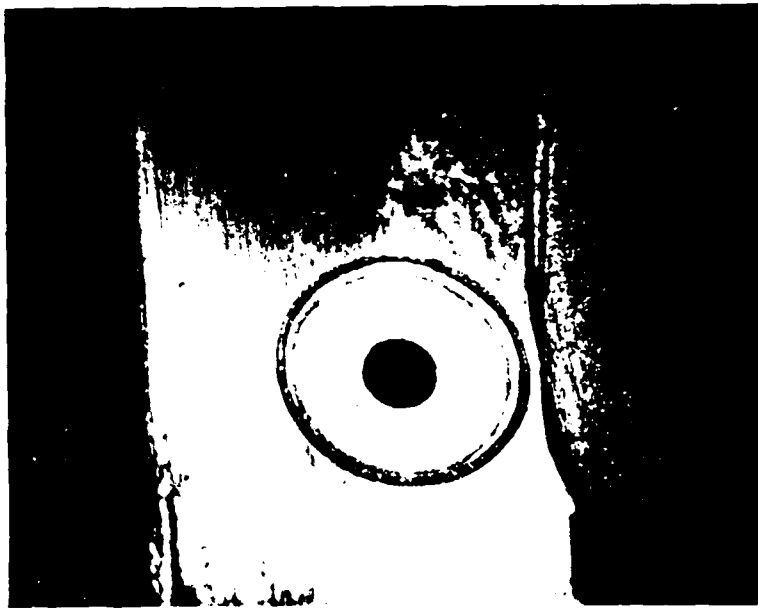


Figure 22. Smith and Wesson Recoil Plate after Firing Remington Ammunition.



Figure 23. Smith and Wesson Recoil Plate after Firing Smith and Wesson Ammunition.



Figure 24. Colt Recoil Plate after Firing,
Remington Ammunition.



Figure 25. Colt Recoil Plate after Firing,
Smith and Wesson Ammunition.

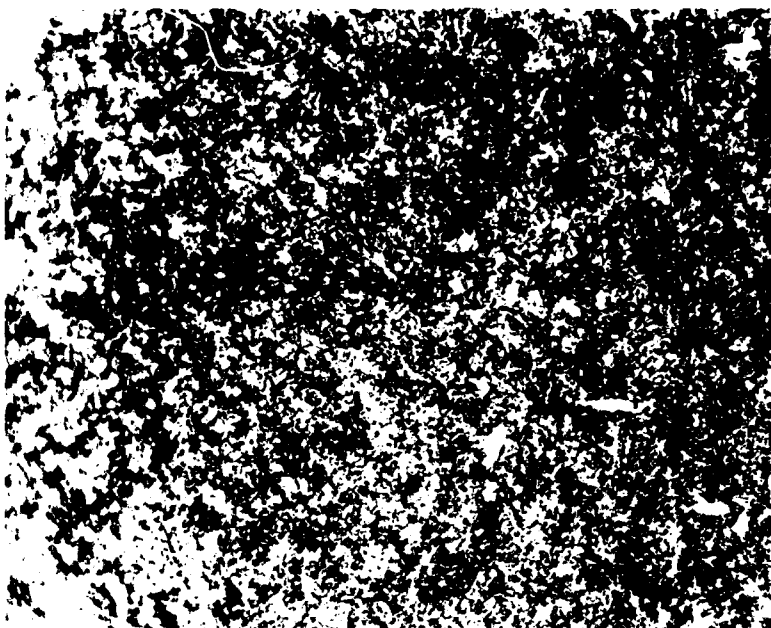


Figure 26. Photomicrograph of Colt Cylinder (250X).

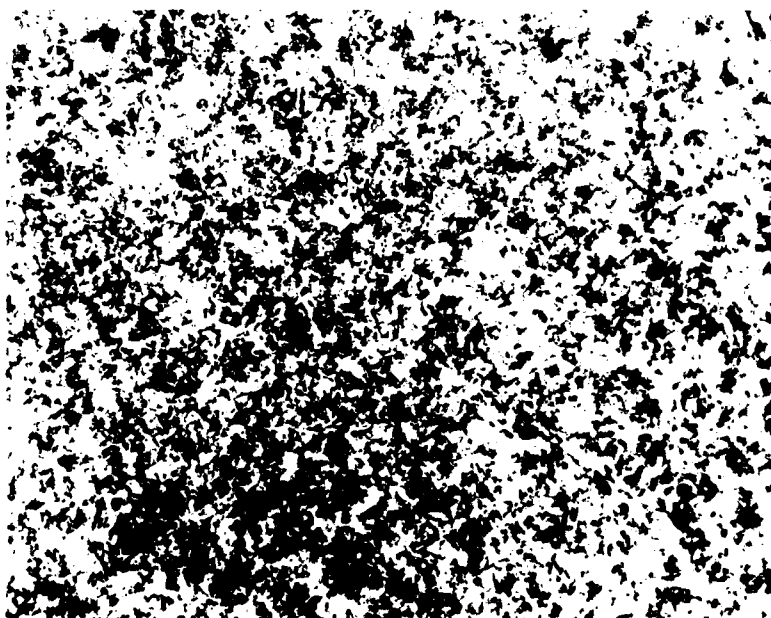


Figure 27. Photomicrograph of Smith and Wesson Cylinder (250X).

etched several times to make certain any apparent flaws were artifacts of the polishing procedures. No flaws were found. Both microstructures show tempered martensite in a presumably wrought structure without inhomogeneities on either a microscopic or macroscopic scale. No porosity, non-metallic inclusions or alloy segregation were apparent. No fatigue or quench cracking was apparent.

Hardness measurements were made on the Colt and Smith and Wesson cylinder surfaces which had been etched and polished. A dozen readings were made on each. The Colt averaged a Rockwell "C" hardness of $37.5 \pm .8$. The Smith and Wesson averaged a Rockwell "C" hardness of 45.7 ± 1.2 . Converting these to Brinell hardness one gets for the Colt, Bhn 347, and for the Smith and Wesson, Bhn 434.⁷

⁷ "Metals Progress Databook 1977," pages 138-139, American Society for Metals, Metals Park, Ohio, June 1977.

IV. DISCUSSION AND CONCLUSIONS

a. Static Pressure Measurements on the Cylinders.

As seen in Figures 26 and 27, the microstructure of the cylinders is tempered martensite. Tempered martensite structures are, as a class, characterized by relatively high toughness at any strength level. The usual mechanical properties of any steel with this microstructure, regardless of the composition, can be generally predicted within plus or minus 10 percent by its hardness.⁸

Using the two measured hardnesses of Bhn 347 and Bhn 434, one can estimate tensile strengths of 169 ksi and 220 ksi for the Colt and Smith and Wesson, respectively.⁹ Similarly, one can estimate yield strengths of 155 ksi and 200 ksi for the Colt and Smith and Wesson, respectively.⁸

Many steels exhibit what is known as a "fatigue limit", or "endurance limit". This is a limiting stress below which an infinite number of stress cycles can be applied without causing fatigue failure. Based on the tensile strengths just estimated above for the Colt and Smith and Wesson (169 ksi and 220 ksi, respectively), one can predict fatigue limits on polished fatigue test specimens made of the same steels of 85 ksi and 100 ksi for the Colt and Smith and Wesson, respectively.¹⁰

If one assumes an elastic modulus of 30 million psi for the steels (a very good approximation), then the strains measured on the Colt and Smith and Wesson cylinders (2766 $\mu\epsilon$ and 2519 $\mu\epsilon$, respectively) would imply peak stresses during firing of the Smith and Wesson ammunition of 83 ksi and 76 ksi for the Colt and Smith and Wesson, respectively. The situation is summarized in Table III.

TABLE III

	<u>Colt</u>	<u>Smith and Wesson</u>	<u>Source or Reference</u>
Deduced Ultimate Tensile Strength for Cylinder Steel	169 ksi	220 ksi	9
Deduced Yield Strength for Cylinder Steel	155 ksi	200 ksi	8
Deduced Fatigue Limit for Polished Specimens	85 ksi	100 ksi	10
Deduced Fatigue Limit for Notched Specimens	35 ksi	35 ksi	10
Estimated Peak Stress Experienced During Firing	83 ksi	76 ksi	Static Pressure Measurements

⁸ "The Making, Shaping, and Treating of Steel," Harold McGannon, Ed., pages 1091-1092, 9th Edition, United States Steel Corp., Pittsburgh, Pa., 1971.

⁹ Ibid., page 1239.

¹⁰ Ibid., page 1253.

In addition to the cyclic applied stress caused by firing rounds in the chamber, there may be stored residual stresses as a result of previous firings. This is one implication of the difference in the response of the Smith and Wesson to static pressure before and after firing. The change in strain could either imply a reduction in elastic modulus (not likely), or a stored residual stress. The difference in strain $(2519 - 2249) = 270 \mu\epsilon$ would correspond to a residual stress of 8.1 ksi if one again assumes a modulus of 30 million psi.

There are various ways to treat the problem of the fatigue limit for a static residual stress imposed on a specimen exposed to cyclic loading. In general, having an average applied stress not equal to zero (which is another way of saying a static residual stress added to a cyclic stress) reduces the fatigue limit. Various empirical relations (or "laws") have been evolved to approximate the change in fatigue limit under these conditions.¹¹ The two most common linear ones are "Soderberg's Law" and the "Modified Goodman Law", and they are represented in Figure 28. A given point on one of the lines representing one of the "laws" corresponds to the maximum permissible applied cyclic stress (or fatigue limit) as given on the "y" axis for the corresponding applied static stress as given on the "x" axis.

Any stress combination "below" the line will not cause fatigue failure, while any stress combination "above" the line will lead to fatigue failure.

Figures 29 and 30 show the estimated cylinder stresses would fall in a plot of this general type for the Colt and Smith and Wesson, respectively. Only one point (an "x") is plotted in Figure 29 for the Colt. Two points are plotted in Figure 30 for the Smith and Wesson. The "x" corresponds to the estimated cyclic stress due to firing. The "o" corresponds to the combination of this cyclic stress and the 8.1 ksi residual static stress implied by the measured shift in the pressure response of the Smith and Wesson cylinder. We assume here that the sign of the residual stress is such that it would be deleterious, not beneficial, to the fatigue limit. In Figures 29 and 30 it can be seen that the Colt is seeing cylinder stresses very close to its fatigue limit, while the Smith and Wesson is not, even though the effect of possible residual stresses have been considered in the case of the Smith and Wesson.

b. Eddy Current Detector Measurements on Recoil Plates.

It should be noted that the low-pressure ammunition firings on both Colt and Smith and Wesson gave recoil plate damage indexes very similar to those produced in the calibration tests on dummy recoil plates, in that after five rounds were fired the index decreased, after which it began to increase. This is not true for the damage indexes found after use of the high-pressure ammunition, for in these cases the index begins to rise immediately. Since the damage index minimizes at 15 blows for both the Colt and Smith and Wesson materials in the calibration tests, but minimizes at 5 firings for low-pressure firings and less than 5 for high-pressure firings, it is concluded that damage proceeds at a higher rate for the recoil plates with their center holes than with the solid sections used in the calibration tests.

¹¹ "Metals Handbook," 8th Ed., Vol. 10, pages 103-104, American Society for Metals, Metals Park, Ohio, 1975.

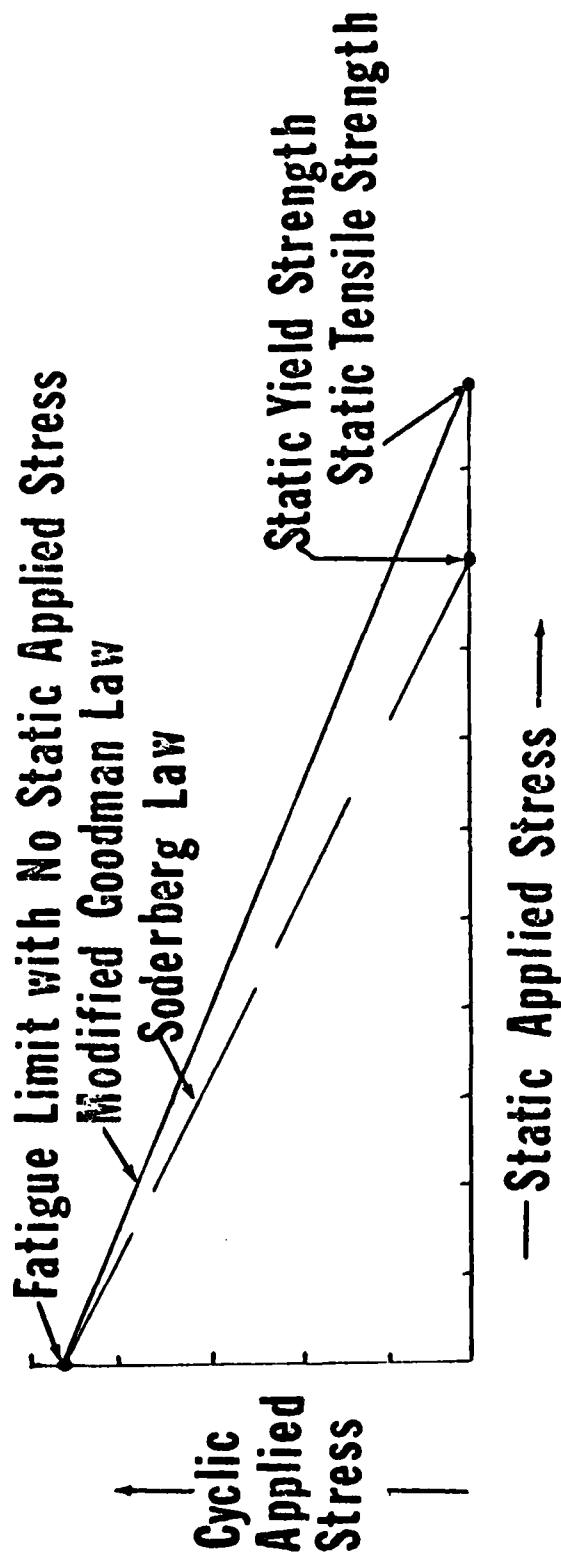


Figure 28. Sketch of Empirical Laws for Change of Fatigue Limit with Simultaneous Cyclic Applied Stress and Static Applied Stress.

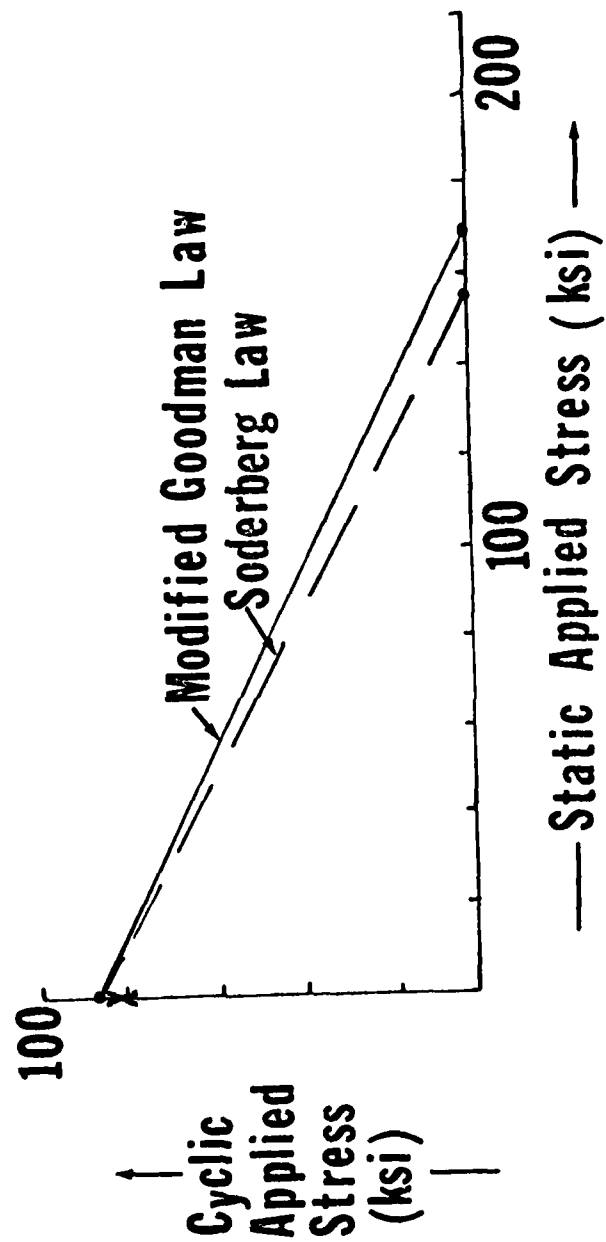


Figure 29. Fatigue Analysis of Colt Cylinder

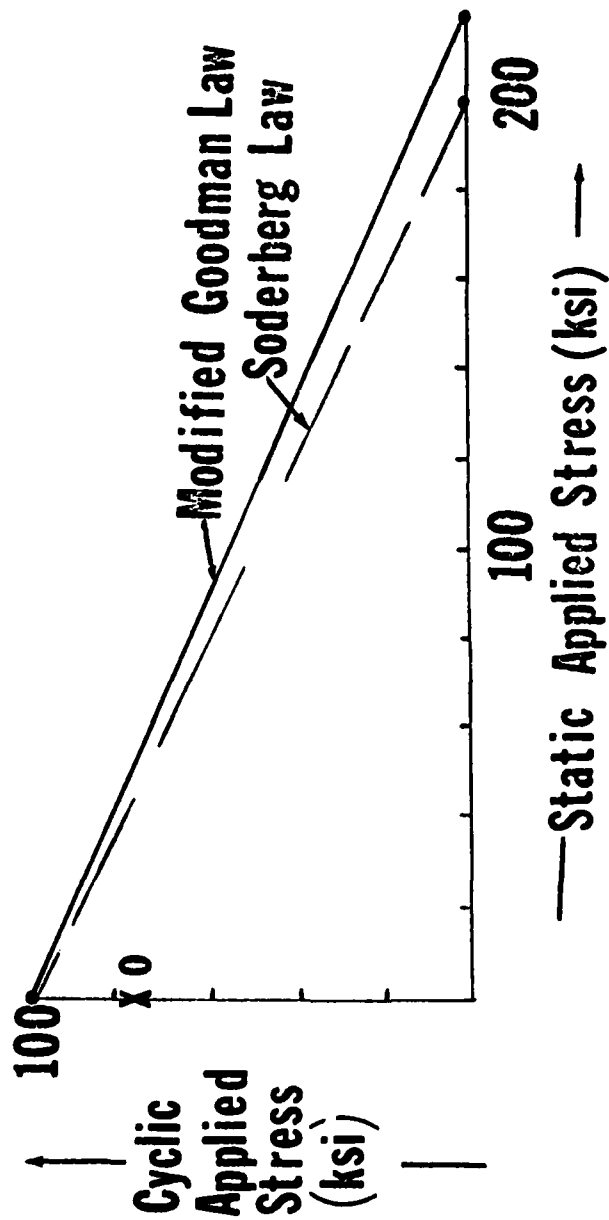


Figure 30. Fatigue Analysis of S & W Cylinder

The relatively constant values at or near the 100 index indicates that the instrument probably should have been set at a lower, more appropriate zero so that the continuing damage could be monitored. The wide swings in the damage index noted especially in Figure 14 or Figure 19 are real and can probably be attributed to stress relief due to redundant working.

It should be mentioned that in the firing tests, the chambers were kept lightly oiled to simulate a cleaned and oiled weapon. A light oil film almost guarantees that the cartridge will not grip the chamber walls, but rather move to the rear and impact the recoil plate when fired.¹² During the tests the spent cases always removed freely and easily from the chamber.

c. Observations on Recoil Plates, Firing Pins, and Cylinders.

Considerable damage in both Colt and Smith and Wesson has been done by the firing pin which in its dynamic forward thrust does not fit the hole and rolls the metal plastically toward the cartridge case. Subsequent firings push this "extrusion" back toward the firing pin. All of the metal appears to be intact after firing fifty rounds, but such movement indicates a high stress/high strain fatigue displacement which will obviously lead to fracture around the firing pin hole early in the gun's firing lifetime. This in turn might lead to a problem with jamming or breaking off the firing pin.

The cross-section of the firing pins themselves seem unusually asymmetric. This means a lack of diametrical control which is surprising for a part required to fit well into a small hole while moving swiftly.

The microstructure of the cylinders for both Colt and Smith and Wesson showed sound metal.

¹² "Handbook for Shooters and Reloaders," P. O. Ackley, page 140, Publishers Press, Salt Lake City, Utah, 1962.

V. SUMMARY

It was determined that the Colt Model D5540 (Diamondback) and the Smith and Wesson Model 15-3 .38 Special revolvers with 4-inch barrels were the handguns most representative of those in use by law enforcement officers among those handguns made available to Marvalaud. Remington 158-grain lead round-nose was determined to be the most representative ammunition. It was selected for use in our firings as the low-pressure ammunition. Smith and Wesson 158-grain jacketed hollowpoint "+P" was selected as the high-pressure ammunition largely because it was the highest pressure of those tested. Indeed, it has a higher chamber pressure than most commercial .357 magnum cartridges.

For our tests, one Colt Model D5540 fired fifty rounds of low-pressure ammunition, while a different Colt Model D5540 fired fifty rounds of high-pressure ammunition, exclusively. The same arrangement was used for the two Smith and Wesson Model 15-3. Measurements were made after each five rounds.

It was found that the peak pressures experienced when firing the Smith and Wesson "+P" ammunition carry the Colt cylinder very near its estimated fatigue limit, while the Smith and Wesson cylinder remains well below (as seen in Figures 29 and 30). It is interesting that a note appearing in "The American Rifleman" quoted Colt Industries as not recommending use of "+P" .38 Special ammunition in its D-frame revolver line (of which the Model D5540 is one).¹³ Our measurements would support that recommendation.

In both the Colt D5540 and Smith and Wesson Model 15-3, the Halec instrument proved to be a powerful tool for measuring the onset of plastic deformation in the body of the recoil plates, which occurs after very few rounds are fired. The instrument resolved the initial differences between firing low-pressure and high-pressure ammunition. Considerable redundant deformation of the recoil plate is indicated by the Halec measurements. One would assume that plastic deformation of such a critical part is not desirable.

For both the Colt D5540 and Smith and Wesson Model 15-3, the visual examination of the edge of the hole in the recoil plate showed severe deformation with a high probability of fracture of material around the hole early in the firing lifetime. It would appear that the recoil plates for both Colt and Smith and Wesson could benefit from redesign.

¹³ "The American Rifleman," page 12, March 1976.

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1. Contract No. Tir-25965, an agreement between the United States Government, Department of Treasury, and H. P. White Laboratory, Bel Air, Md., Vols. II and III, Sept. 1971.
2. LEAA Police Equipment Survey of 1972, Vol. V: Handguns and Handgun Ammunition, LESP-RPT-0005.00, August 1975.
3. Test Report - "Interior Ballistic Tests of a Limited Sample of a Variety of Commercial Handgun Ammunitions," prepared for U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Md., by H. P. White Laboratory, Inc., Bel Air, Md. 21014, August 1976 under P.O. No. DAAD05-76-M-A498.
4. Micro-Measurements Series CEA-06-125UW-120 Strain Gages.
5. We were unable to compare gage zero readings before and after firing the Smith and Wesson because of a change in the bias or "balance" voltage setting of the strain gage bridge during the intervening period.
6. We wish to express our appreciation to Mr. Harold Waterman of Colt Industries and Mr. H. E. Sibley of Smith and Wesson for this information as well as samples of their recoil plates (or hammer nose bushings).
7. "Metals Progress Databook 1977," pages 138-139, American Society for Metals, Metals Park, Ohio, June 1977.
8. "The Making, Shaping, and Treating of Steel," Harold McGannon, Ed., pages 1091-1092, 9th Edition, United States Steel Corp., Pittsburgh, Pa., 1971.
9. Ibid., page 1239.
10. Ibid., page 1253.
11. "Metals Handbook," 8th Ed., Vol. 10, pages 103-104, American Society for Metals, Metals Park, Ohio, 1975.
12. "Handbook for Shooters and Reloaders," P. O. Ackley, page 140, Publishers Press, Salt Lake City, Utah, 1962.
13. "The American Rifleman," page 12, March 1976.

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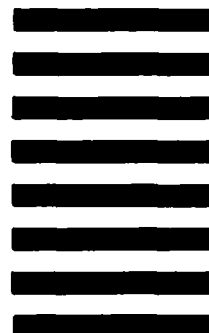


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